ROAD ENGINEERING

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BY

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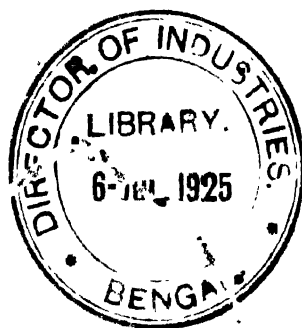
PREFACE

THIS volume is an attempt to give in a concise form the technology of road construction in the light of the new conditions created by modern traffic. Many excellent works on this subject have been already published, and the author is conscious of the difficulty of improving upon, or adding to, some of the information contained therein.

There has been a tendency in the past to treat this subject independently of the engineering features of the vehicles using the road, and it is upon this point that the author wishes to concentrate in order to treat the question of vehicle design and road construction as one branch of engineering. Mathematical considerations can no longer be omitted from the curriculum of the road engineer, since the future development of road construction simply demands such treatment.

The advent of the new motor license duties of the year 1921 marked the beginning of a new era in road development, more especially because these duties place a much larger sum of money at the disposal of the road authorities for improvement and maintenance than has been the case hitherto. Whether these duties are varied or not, the principle is established that the traffic using the road should bear the cost.

It is to be hoped that, in the near future, there will be a much more rapid development in the use of pneumatic tyres for commercial vehicles, omnibuses, and charabancs, with a much lighter taxation than that of the solid rubber-tyred vehicle. There appears to be some ground for thinking that ultimately the taxation authorities will offer encouragement in this direction with a view to reducing the damage to roads.

The author is indebted to the Institution of Civil Engineers for the facilities afforded him by the privilege of abstracting the

articles on road construction for the quarterly Engineering Abstracts from current periodicals.

A vast amount of research work is being carried on in other countries, especially America, details of which are collected and summarized in these volumes together with abstracts of all other branches of engineering science. The more important records of such work will be referred to in this volume, so that engineers in this country will have the essentials of road engineering practice abroad available for reference.

It is somewhat difficult to realize that here in this country, where the road system is well developed as compared with countries like America, Canada, Australia, and India, many of the roads themselves both in construction and lay-out must undergo considerable transformation and reconstruction to meet the modern conditions of traffic. Good roads and a good road system are among the first requirements of civilization and social development.

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ROAD ENGINEERING

INTRODUCTORY

The End of a Chapter

No historical review of road development would possibly omit to give the year 1914 as the end of one chapter and the beginning of another. There is no doubt that the Great War marked very distinctly the rapid development and increasing utility of mechanically propelled vehicles. Prior to this period the pleasure vehicle and the motor omnibus were the main channels of progress for this kind of traffic. The F.W.D. (four-wheel drive) vehicle is an example of a War product, and it is fairly certain that this means of propulsion would have been of much later origin had it not been for the exigencies of the War. It is desirable also to relegate the waterbound macadam road to this pre-War period, and the Author does not propose to deal with this method of construction at any great length, there being already many excellent works on the subject. Waterbound macadam, therefore, will be considered as outside the realm of practical politics where modern traffic is concerned. The Author has endeavoured to concentrate on the most advanced methods of road construction and has not entered into any great detail in the case of work already covered by existing books.

Earlier Types of Roads

One of the earlier type of road pavements adopted in this country was the boulder paving, consisting of large irregular boulders 6 to 9 in. deep, possessing naturally large and irregular joints, especially after wear had taken place. Other roads were paved with stone blocks which, however, were little better than the boulders. Small boulders or cobble pavements built with sea-shore boulders have been used very extensively and are still in existence in many large towns to-day ; they are roughly egg-

shaped and are placed on end so as to give as great a depth as possible. Cobbles have also been used extensively for footpath work, but these are usually much smaller in size than those used for road work.

Sett paving of various kinds has superseded cobbles and boulders, and in many cases is giving excellent service to-day.

Earth and clay roads are still in use in remote parts of America, prairie districts, etc., where grading, harrowing, ploughing, scraping, etc., are carried on by machinery in a thoroughly scientific manner. Gravel roads are also used in like manner where conditions are favourable.
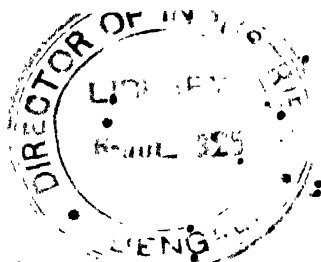
ROAD ENGINEERING

CHAPTER I

SUBSOILS AND DRAINAGE

OBVIOUSLY, before proceeding to deal with the problems that arise from the construction of the wearing surfaces of roads, some attention must be given to the subsoil upon which the structure of the road rests. The main difficulty in road foundations is to secure a uniform and firm condition of the subgrade, which will enable heavy and concentrated loads to be carried without fear of structural failure. The subsoil varies to such a degree, not only in different districts, but also in different sections of the same road, that it is impossible to do more than lay down general principles ; much must be left to the discretion of the engineer, who will have become familiar with the local conditions in the process of laying the sewers, etc.

Supporting Value of Soils

As the result of practical experience, it is well known that roads identical in type and design are not always equally successful, and this variation may frequently be traced to the differing support offered by the respective subgrades. A table is appended giving the supporting values of subsoils.

Type of soil.	Per sq. ft.
Made ground	$\frac{1}{2}$ ton.
Soft clay	1 ton.
Hard clay or loam	2 to 4 tons.
Dry compact sand	2 to 4 tons.
Dry coarse gravel	4 to 7 tons.
Ordinary rock	4 tons and upwards.
Hard rock	9 tons and upwards.
Loose beds with filling	2 tons.
Loose beds with concrete	3 tons.

Tests for Bearing Power

The following synopsis from an article in " Public Roads " (U.S.A.), is a summary of a number of tests for determining the bearing power of subgrade soils.

The tests were carried out to determine which subgrades are most satisfactory. The samples consist of 0·2 cu. ft. of soil from the field, which is broken in a mortar with a rubber-covered pestle to pass a ¼-in. screen. The portion retained is considered as gravel, and is only used for determining the mechanical analysis and bearing power ; the remainder is passed through a soil pulveriser consisting of two adjustable electrically driven rubber rolls.

Mechanical Analysis (indicating fineness).

A 500-gram sample of the soil is passed through a 10-mesh sieve, and a 50-gram sample of this fine sand is then placed in a glass jar, 15 cm. by 8 cm., with screw top ; 200 c.c. of water and 5 c.c. of dilute ammonia water are added ; and the whole is revolved in an agitator for 1 hour. The contents are allowed to settle for 8 min. and most of the water is syphoned off. The soil is again washed, settled, and syphoned until clear after sedimentation. It is then dried, and a sieve analysis is made with standard 20-, 50-, 100-, and 200-mesh sieves. This indicates the grading—i.e. whether the material is coarse or fine.

Water-holding capacity.

A sample of the soil contained in a box, 6 cm. diameter and 1 cm. high, the bottom of which is perforated with 150 holes, each $\frac{1}{32}$ in. diameter, is, after weighing, submerged in a pan of water on a brass triangle for one hour. It is then blotted off, weighed, and the result compared with a dry soil.

Comparative bearing power.

Soils—coarse or fine—are first mixed by hand with water and moulded under an initial pressure of 30 lb. per sq. in. A brass cylinder of area 10 sq. in. is attached to the moving head of a 20,000-lb. (Universal) testing machine, which has a brass ring for confining the soil vertically and ensuring perpendicular

loading, and also two ⋅001 in. Ames dials for measuring the penetration. The weight of the soil and its volume before and after compression are noted, and the specific gravity and values for density under different conditions of moisture and initial compression are computed. There are also tests for determination of vertical capillarity, air shrinkage, and time of slaking. The above three tests provide an excellent indication of the strength of a soil under the various conditions of weather, loading, and natural drainage.

Although different types of soil differ from each other in their bearing capacity, they also vary in themselves under a diversity of conditions, such as altitude, geographical position, etc.

The chief factors that contribute to the loss of bearing power of a particular subgrade are :—

1. A friable condition of the soil.

2. The presence of water to saturation.

In the first case, the ground may be consolidated by rolling, or it can be strengthened by the addition of broken bricks, breeze, brushwood, or some similar material that will combine with the existing soil and give it " body." In extreme cases the whole bed of the road must be excavated and remade. It should be noted in this connection that a reinforced concrete foundation will efficiently support the road crust over any but the most severe conditions of subgrade.

Friability, as a condition, argues also lack of elasticity. This factor is elaborated in a series of tests of Impact on Pavements carried out by the Bureau of Public Roads, U.S.A.

It was found that the subgrades under test failed to return to their initial elevation when the pavements they supported were subjected to impact, whereas the concrete-slab pavement itself did spring back after each blow. Each succeeding blow caused the slab deflection to increase, in ratio to the " looseness " or friability of the soil and also to the degree of water content.

In the limit, the subsoil ceases to offer any support and the slab acts as a beam. These tests do not conform absolutely to the conditions existing on actual pavements, but they have an application in the case of a subgrade which offers a varying or

uneven support, as the consolidated portion will resist the stresses imposed upon it by the traffic and the " loose " portion will tend to deform to a greater or lesser degree. Obviously, failure can be expected under these conditions.

There is a wide divergence of opinion as to the effect of water on subsoil, and there is considerable scope for research work in this connection.

The Author is of the opinion that the bearing power of most soils is not greatly affected by the addition of water up to the moisture equivalent—i.e. the percentage of moisture retained in the soil when subjected to a centrifugal force equal to 1000 times the force of gravity—especially where the supporting value is uniform, but, after a certain point, which varies with the nature of the soil, there is a rapid reduction in bearing power until complete saturation is reached, when it is of little or no value as a support.

Methods of Effecting Subsoil Drainage of Roads

In this connection it is sometimes possible to tap the subsoil water into surface drains, or into a sewer trench ; in country districts deep drainage ditches may be constructed, or the subgrade may be treated with crude water-gas tar at the rate of about 1·7 gal. per sq. yd. This renders the shoulders, or grass margins, and the insides of the ditches waterproof from rainfall percolation, and horizontal capillarity. This latter difficulty can sometimes be circumvented by a cut-off wall of cement or earth mixed with crude water-gas tar on each side of the road before it falls into the ditch, or a tile drain may be constructed to run from below the channels into the ditch.

One or other, or a combination of several of these methods, will usually be found to meet the local conditions with success.

In all cases of deficient or badly drained subsoil, the road should invariably be laid upon a *reinforced concrete* foundation.

The road laid at Loch Doon for the Aerial Gunnery School in 1917 is an interesting example of the weight-distributing capacity of reinforced concrete.

The first road of macadam, though of considerable depth of metal, gradually subsided in the boggy ground and became

useless. A reinforced-concrete road 7 to 9 in. thick, 16 ft. wide, and 700 yd. long, was then tried as an experiment. The ground was drained by field drains and ditches, as shown in Fig. 1, prior to laying the concrete, which was actually laid on top of the grass without even rolling. The result was an entire success and exceeded the expectations of the designers. Further reference to concrete foundations is made elsewhere.

FIG. 1.—Example of Subsoil Draining under Concrete Slab.

Where the level of the road is below the natural level of the subsoil water, as, for instance, in a cutting, the question of drainage becomes intensified.   In cases of this kind the ground can be ploughed and harrowed, treated with water-gas tar at the rate of about 4·0 gal. per sq. yd., thoroughly rolled and consolidated with screened gravel, and frequent tile drains constructed to connect with longitudinal side drains : the latter are laid one on each side of the road, as this is a good position for draining subsoil water, and moreover it drains the ground at the point where resistance to side thrust is needed.

Gullies on Road Surfaces

The location and type of gullies requires careful consideration in order to secure rapid and efficient drainage, and also to cause the minimum of inconvenience to traffic.

Much depends on the headfall or longitudinal gradient of the road. Where this is moderate the gullies may be placed well apart and no danger from high velocities of surface water during storms will occur. A steep longitudinal gradient is not to the advantage of the surface drainage, nor the surface of the road, nor to the road user.

It is a common practice to place gullies in the channels with the grids " dished " or lowered about 1 in. below the level of the channel itself. This is not desirable, as a sudden jolt or drop at this point of a vehicle may do serious damage to the gully, besides shaking goods carried by the vehicle. No doubt this

disadvantage is the main reason for adopting the vertical inlets and gullies in or under the kerbs, a method which is very popular in continental towns. It has, however, the disadvantage of making it necessary to take up the footpath or disturb the kerb when the gullies require cleansing. Fig. 2 shows a concrete pavement gutter introduced during the War when other materials were difficult to obtain.
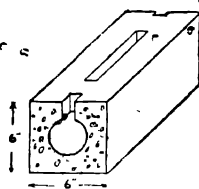
FIG. 2.—Concrete Pavement Gutter.

There are various types of gullies, mainly in earthenware, in use at the present time embodying the catchpit and trap at the outlet to prevent the rise of noxious sewer gas.

The Author has designed a concrete gully, consisting of monolithic chamber containing a catchpit and a trap, formed by means of slabs fixed in grooves with putty or non-setting cement. The slabs are easily removed and the trap cleaned without difficulty.

The arrangement of the gully is shown in Fig. 3. One feature
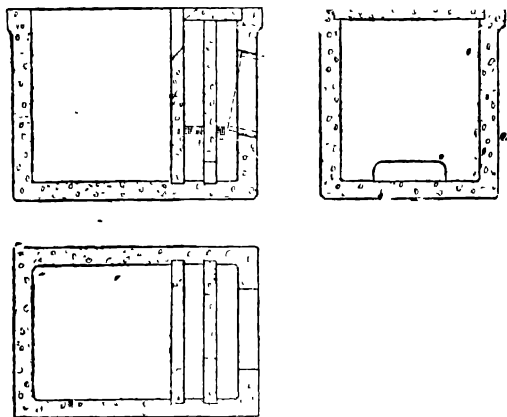
FIG. 3.—Detail of Concrete Gully.

of this construction is that the gully can be cast in position in the ground by the aid of an outer sheet-iron mould, which can be withdrawn whilst the concrete is still wet, provided that suitable earth is well rammed behind it : a light cast-iron or wooden

inside mould is used, slightly tapered, which remains until the concrete is set.

The general requirements for an efficient gully are as follows :—

1. It should be of sufficient capacity to catch by settlement the heavy detritus or other solid matter washed from the road surface and to require emptying only at moderate intervals.

2. It should have an efficient and accessible trap to prevent the rise of sewer gas.

3. The drain connecting the gully to the sewer should be accessible for cleansing in case of stoppage—if possible from behind the kerb or edging or from the gully itself, and not from the road surface.

4. It should be fixed in concrete so as to be free from disturbance by traffic.

5. The grid should be of sufficient size to take ordinary road matter, but to reject without clogging larger foreign matter which might stop up the drains.

In view of modern waterproof surfaces and decreasing horse traffic the size of the catchpits may be reduced.

The Frequency of Gullies.

The distance apart for fixing gullies on a highway is a matter which should be left to the discretion of the engineer. At the same time certain rules can be laid down for the determination of a suitable distance. This is influenced by the following factors :—

(a) Longitudinal gradient.
(b) Cross-fall from centre to sides or from one side to the other.
(c) Width of roads or junction of roads.
(d) Occurrence of footpaths or crossings over footpaths.
(e) Kind of material used for road surface.
(f) Whether for town or country conditions.

For roads of flat gradient longitudinally the distance apart should not exceed 20 yd. in each channel. This allows of drainage in the channels at suitable improved gradients from a summit to the gully. Generally this means an increased expenditure

compared with a road having more gradient, but if desired the size of the gullies and grids may be reduced somewhat as a means of economy.

Whilst the road of medium gradient, i.e. 1 in 100 to 1 in 150, is the most satisfactory to treat for surface drainage, the flat and the hilly roads, as extremes, are the most difficult. In the former case, great care is necessary to keep the shape of the road for as great a width as possible, to facilitate cross-fall and to be safe for traffic.

In hilly districts there is always a danger that the rapid flow of water, during storms of continuous heavy rains, will scour out channels in the road's surface : the foot of a steep hill is the very place where the greatest speed of traffic is attained, and excessive vibration is set up, so that any scouring of the surface due to heavy rains will rapidly cause disintegration or destruction of the surface for a considerable length. Where a large volume of water requires to be drained off at one point, two or more gullies and grids may be used for the purpose.

Gullies under Footpaths.

The question of placing gullies off the road in town or suburban areas is one which demands immediate attention. Where traffic is congested, it invariably happens that heavy vehicles travel with the inner wheels in the channel. This results in a serious impact when the wheels strike the gully, the results of which have been previously alluded to. A partial solution of this somewhat difficult problem is to place the grid partly under the kerb and partly in the channel.

The importance of smooth channels draining towards the gully cannot be too strongly urged. Sett channels are useful on macadam or tar-macadam roads, but on sett-paved roads concrete or stone-block channels are desirable on the flatter gradients.

The drainage of very wide intersections of road surface or otherwise very wide roads is not usually performed by gullies in the centre of the highway, as this would require depressions in the surface which would be dangerous to traffic.

Drainboxes are frequently utilized in connection with tram-

ways at the foot of hills, as the rails form good water carriers in rainy weather, but they are somewhat unsatisfactory, as the small or limited openings in the rail grooves easily become blocked.

Note.—See Thomson's " Modern Sanitary Engineering," Vols. I and II, Glasgow Civ. Eng. Series, for further information *re* gulley traps for surface water drainage, etc.

CHAPTER II

IT is not within the scope of this book to deal with the question of the treatment of bridges ; it is only proposed, therefore, to outline general conclusions regarding surfacing and probable impact or stresses likely to be encountered in bridge work.

Paving Suitable for Bridges

To be suitable for bridge work a paving must possess :—

    (a) Low tractive resistance.
    (b) Smooth wearing qualities.

The following are four types of paving which conform to these requirements. These refer to streets or suburban roads :—

    1. Asphalte, including bituminous macadam.
    2. Wood blocks.
    3. Dressed granite cubes.
    4. Concrete.

The two first mentioned possess elastic qualities which have the effect of resisting impact under traffic. Bituminous macadam is well suited for many bridges on country roads.

As a general rule it is advisable to reduce the thickness of the road slab to the smallest permissible dimensions in order to reduce the dead load on the bridge.

Concrete paving is decidedly the most suitable in this capacity, because it forms a wearing surface as well as a stress member. An allowance must be made for the wearing surface in addition to the thickness computed for the bridge stress.

Small granite cubes laid on concrete or reinforced concrete form a reliable wearing surface without the dead weight on the

bridge that would follow from the use of the larger setts. The jointing of these setts may be done with cement grouting, and in this case the setts may form part of the compression section of the beam slab.

In estimating the probable impact on the highway of a bridge it is essential to distinguish between live load and impact.

It has been stated by an authority on this subject, Prof. C. E. Inglis, that in the case of a 20-ft. span of steel joists carrying motor lorries travelling at the rate of 20 miles per hour, the increment of stress, assuming no jolting, was only 3 or 4 per cent, and the application of load was comparatively sluggish. The percentage allowance for impact should clearly be a function of the span as in railway bridge design.

Other facts which should be considered are the nature and speed of the load[1] and the natural period of vibration of the bridge or bridge members.

A reference to the impact tests in Chapter XVI will indicate the allowance which should be made for impact from motor lorries for a 2-in. drop or obstruction.

In an article in " Engineering News Record," W. Whited, Esq., deals with this question of Impact on Bridges in detail. He states it is his opinion that there are two definite impacts on bridges—when the wheel strikes an obstacle and when it jumps off the obstacle—and suggests that the impact allowance, based on a 3-in. obstruction, should be $\frac{2}{3}$ the sprung load at 15 m.p.h., and 0·8 for a 4-in. obstruction, so that an allowance of $\frac{2}{3}$ the sprung load on any wheel applied at whatever point of the bridge floor will give a maximum stress in the given member, represents a sound basis for computing impact. Experiments are to be made by the Standards Association and the Ministry of Transport to determine impact allowance.

Reinforced concrete can be used to advantage to strengthen bridges constructed to meet only the requirements of a previous age, and render them sufficiently strong to carry modern traffic. A " carpet " of bitumen has been used successfully in the

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[1] Pamphlet No. 153, Part 3, dealing with loads and stresses, issued by the British Engineering Standards Association, gives figures for Impact on Road and Railway Bridges.

States, to strengthen plank road bridges, the elastic properties of the bitumen being of special value in this particular.

Standard Loads for Highway Bridges

The Ministry of Transport has issued details of the standard load which will produce the maximum stress in any bridge member, providing that in any train of loads there shall not be more than one engine per 70 ft. of the span of bridge, and that the distance between the centre lines of two adjacent trains of loads is taken as 10 ft.

The actual loads on the bridge include an engine weighing 20 tons and drawing three trailers 13 tons each, as shown in Fig. 4. A further 50 per cent allowed for impact increases this
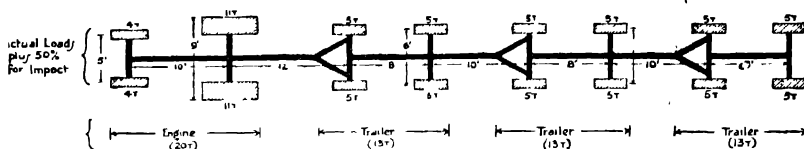
Fig. 4.—Standard Loads for Highway Bridges (Ministry of Transport).

weight to 30 tons for the engine and 20 tons for each trailer. It will be understood, however, that this standard might be regarded as rather stringent for country areas, and perhaps too little for some manufacturing centres; the restriction of heavy traffic to principal roads will largely solve this question.

The series of loads is as follows :—

	Axle loads.	Distance from front axle.	Width between wheels.
Front axle engine	8 tons	0 ft.	5 ft.
Rear axle engine	22 tons	10 ft.	9 ft.
1. Trailer front axle	10 tons	22 ft.	6 ft.
1. Trailer back axle	10 tons	30 ft.	6 ft.
2. Trailer front axle	10 tons	40 ft.	6 ft.
2. Trailer back axle	10 tons	48 ft.	6 ft.
3. Trailer front axle	10 tons	58 ft.	6 ft.
3. Trailer back axle	10 tons	66 ft.	6 ft.

The following appears under the heading of " Highway Bridges " in the Report on the Road Fund, 1921–2, issued by the Ministry of Transport :—

A large number of schemes have been under consideration for the improvement, strengthening, or reconstruction of highway bridges, many of which fall considerably short of modern traffic require-ments—witness the warning notices displayed on the majority of these structures in the more remote parts of the country.

It is obviously desirable for a uniform standard of strength to be applied to bridges on all the principal highways, and with this end in view a standardized loading for highway bridges has been pre-pared—*see* the relevant diagram. The aim has been to ensure that any bridge, towards the cost of which a grant is made or a loan recommended, shall be so designed as to carry any traffic which may come on the road, so that no restriction need be imposed on the use of the bridge. In deciding upon this standard loading, it had to be borne in mind that a bridge is the most important link in the high-way chain, and that a life of at least one hundred years should be anticipated. It was therefore essential that a margin should be allowed to cover the more onerous loading which may be expected in coming years.

It is necessary to point out that this standard loading is only applicable to bridges required to carry normal traffic, and that in certain industrial districts, such as Liverpool, where heavy indivisible loads in excess of 16 tons have to be dealt with, the bridges must be designed of greater strength accordingly. These exceptional cases fall to be considered, in the first instance, by the highway authorities concerned.

The load specified, namely, one traction engine and three trailers, is the heaviest dead load that is permitted for a train of vehicles having steel tyres, and to this dead load 50 per cent has been added for impact. It must be admitted that 50 per cent can only be regarded as an empirical figure, for which it is hoped to substitute an appropriate formula as the result of experiments which are now proceeding.

The principal difficulty encountered by highway authorities in the matter of bridges arises in the case of those structures which are maintainable by undertakings, such as canal companies, railway companies, etc., whose liability is limited to the maintenance of a structure adapted to the loads and traffic conditions of the period in which the bridge was erected. In these days, when traffic con-ditions have become far more severe than they were in the period of canal construction or in the time of the earlier railway develop-ments, it is evident that the greater number of canal bridges and

many railway bridges need entire reconstruction. Not only is their strength inadequate, but in many cases the width is insufficient and the camber of the bridge unsuitable for fast-moving traffic.

The financial situation of many of the canal undertakings places grave difficulties in, the way of the reconstruction of these bridges. Continuous pressure, however, is being exercised by the Department, and many conferences have been held with a view to drawing up schemes for the apportionment of the cost of reconstruction between the undertaking, the highway authority and the Road Fund. In view of the magnitude of the problem some years must necessarily elapse before the highways of the country, especially in regions traversed by canals, can in this respect be brought up to a standard likely to give complete satisfaction to road users.

In connection with the standardization of bridge design, it may be mentioned that, with regard to carriageways generally, a standard width is now recommended, based on a unit of 10 feet per line of traffic. This dimension applies equally to the carriageway of highways and of bridges, and its adoption has been generally welcomed by local authorities, who have long been seeking guidance on this point. The introduction of such a standard will serve a useful purpose in discouraging the creation of carriageways of unnecessary width, as it is clearly undesirable that intermediate dimensions should be adopted which give an excessive width for (say) two streams of traffic, and an inadequate width for three.

Approaches.

The approaches to a bridge frequently form a gradient, and these should be dealt with in the same manner as described in the Chapter on "Hill Roads."

The use of wheelers, i.e. smooth runners for the track of wheels (Fig. 5), will have the effect of compelling traffic to keep to the rule of the road, which is of great importance on a bridge.

Fig. 5.—Concrete Wheelers for Bridge Approaches and Hills.

Culverts

As in the case of railways, roads have frequently to cross over streams and rivers. In the past these culverts have been mainly brickwork, with a brick arch and possibly brick inverts. This

kind of construction reduces headroom—a valuable requirement for this class of work ; similarly, the arch is unable to provide the necessary cross-sectional area for streams in flood.

It is very necessary to design these culverts to avoid any raising of the road surface above the adjacent level. Reinforced concrete lends itself to this construction by forming a slab top in place of the arch.

The inverts and abutments may also be constructed in concrete or reinforced concrete. One invert is constructed to form a small half-channel to take dry-weather flow and the remaining invert to carry the storm water as shown in Figs. 6 and 7.
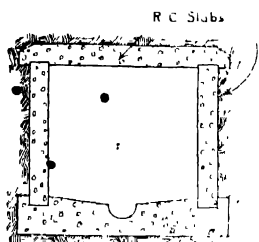
FIG. 6.—Concrete Culvert with Invert for Dry-weather Flow.
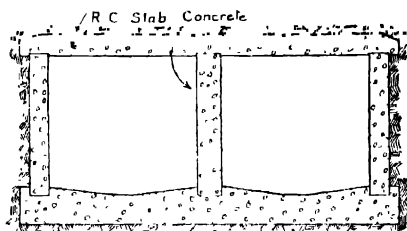
FIG. 7.—Double Concrete Culvert with Limited Headroom and Invert for Small Flow.

Fig. 8 shows the construction necessary for building a square-shaped concrete culvert.

Retaining Walls

The early method of constructing retaining walls in mass brickwork is giving way to small structures of reinforced concrete.

There is considerable scope for the engineer in this class of work, which is economical in construction and easily and speedily erected.

In designing walls of this character, usually in reinforced concrete, the wall is L-shaped in section with a buttress or counterfort between the base and vertical walls at intervals of 10 or 12 ft., as shown in Fig. 9.

Another method is by anchoring back by means of concrete blocks set in the ground (Fig. 10).
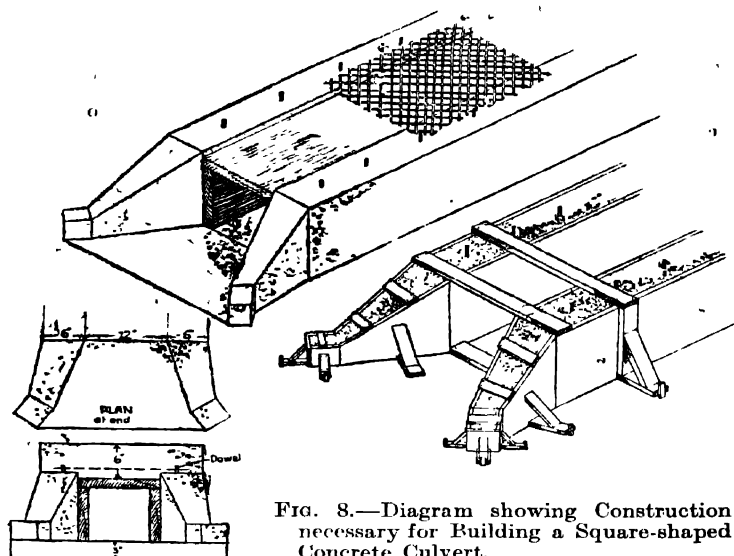
FIG. 8.—Diagram showing Construction necessary for Building a Square-shaped Concrete Culvert.
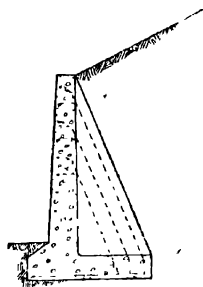
FIG. 9.—Reinforced Concrete Wall (L-shaped).
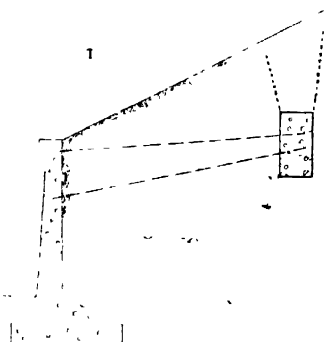
FIG. 10.—Method of Anchoring Reinforced Concrete Wall.
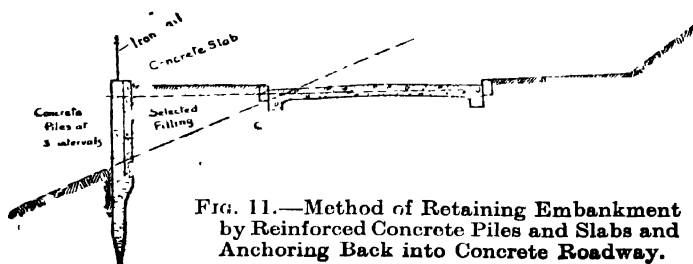
FIG. 11.—Method of Retaining Embankment by Reinforced Concrete Piles and Slabs and Anchoring Back into Concrete Roadway.

Where a road is on an embankment or hill-side, and economy is the first consideration, a satisfactory method is to drive reinforced concrete piles at frequent intervals—the top of the piles to be anchored back into the more solid concrete paving, or foundation. Reinforced slabs are then set against the inside face and earth rammed into position against the slab; thus an economical and structurally sound wall is constructed without shuttering (Fig. 11).

In some cases this construction may be repeated on the opposite side of the road and tie-rods fixed one side to the other, thus locking each pair of piles.

Abutments and wing walls may also be constructed in accordance with this principle of anchoring back into the ground.

Another method of reducing the cost of retaining-wall construction is to build two thin walls in concrete, about 2 or 3 ft. apart, and separated by concrete, or reinforced concrete struts as shown in Fig. 12. The space between is then filled with heavy earth well rammed but drained at the bottom, so that the whole becomes one mass to resist the thrust of the earth.

Fig. 12.—Composite Retaining Wall; an Example of Economical Construction.

Note.—See Gardner's "Earthwork in Railway Engineering," and Ball's "Reinforced Concrete Railway Structure," Glasgow C.E. Series, for further information regarding earthwork and road bridges.

CHAPTER III

THE term " camber " in road engineering implies the convexity of the carriageway or the rise of the centre above the edges or channels of the road. History records that the Romans constructed their stone roads of elliptical shape or camber and that a greater crown was allowed for roads made of inferior materials than for roads built of stone.

The cambered road is the general practice in road engineering to-day. It has been pointed out by Mr. H. R. Mallock, F.R.S., in a paper read before the Institution of Civil Engineers in 1910, that the design of the cambered road was wrong in theory because it was flattest where the flow of water was least and steepest where the flow was greatest, and he suggested that the shape should embody a quickening of cross-fall to the centre. This would produce a ridge line longitudinally along the centre of the road which is obviously quite impracticable. Another suggestion which he made was that the road should drain evenly towards the centre from both sides. This proposal is hardly practicable for the majority of our roads to-day, but having regard to the smoother and more perfect surfaces of modern roads the suggestion is certainly deserving of mention and discussion.

The early history of the Telford and macadam roads shows that a well-cambered surface was considered advantageous for the life of the road. A convexity of about 6-in. rise on a 30-ft. road, as adopted on the Holyhead road, became fairly standard practice, although there is no doubt that a greater convexity than this was desirable to assist in surface drainage and resistance to traffic and weather conditions generally. The importance attached to camber for Telford's construction has in no way decreased with the development of modern traffic. Mechanically

propelled vehicles and their drivers are quite as susceptible to the effect of camber on a road as is the horse-drawn vehicle and its driver. No driver enjoys riding along on the side slope of a well-cambered road.

Smoother Roads—Less Camber.

Fortunately the tendency of modern construction is to produce smoother and harder roads the surfaces of which require much less camber to secure efficient drainage than the water-bound macadam roads. Where concrete enters into the construction, either as foundation or surface, the arching effect once so important is almost unnecessary, since there is little likelihood of local settlements or potholes appearing in the surface.

Where longitudinal gradient or head-fall exists a reduction of camber is permissible on almost any class of road.

The most important point in regard to camber is its influence on the wear of the road itself. Generally the passage of vehicles— except on the heavily trafficked roads where " lanes of traffic " exist in both directions—becomes more or less concentrated at the middle of the road. The narrower the road the more concentrated does this become until, carried to the extreme, the well-known ruts of the farmers' cart-track are formed. It is obvious that a road having a good crown will attract traffic to the centre on the straight sections of road, because the vehicle is better balanced and therefore under no strain in steering. This instinctive habit of road-users is largely responsible for the cost of maintenance on this class of road.

It is incumbent upon the road engineer to devise some means whereby concentrations of wheel traffic, at any rate on the open road, are prevented, and one of the best methods of attaining this desirable object is, where the road surface permits, to reduce the camber.

With a small camber the driver of a vehicle is unable to " feel " whether he is on the crown or not and the natural result is that he automatically keeps slightly to one side of the road according to the rules of traffic, since there is no special advantage in keeping the centre.

Another feature of wear on an excessively cambered road.

where "lanes of traffic" exist and therefore keep to one side, is that the inner wheels become more heavily loaded than the outer ones, owing to the shifting of the centre of gravity, and this causes a corresponding increase of wear, the driving adhesion being obviously reduced on the outer wheels. The Author recollects a case where motor omnibus traffic travelled with the outer wheel on a well-paved tram track and the inner wheels on the macadam shoulder. The macadam showed distinct signs of waviness, whereas the sett paving which was on a concrete foundation showed no wear whatever. This was largely due to the increased weight on the inner wheel acting, of course, on a less rigid material and causing a movement of the road metal towards the channel.

Quite apart from this aspect of camber there is the serious danger of its effect on the rear axle of motor vehicles, which frequently causes skidding : on several occasions the Author has been concerned with cases of accidents caused by rear skidding on a greasy cambered surface. Even a horse-drawn vehicle will skid or slip towards the channel on a road of this kind, but the mechanically propelled vehicle will skid at the rear wheel much more rapidly, especially if the driver endeavours in alarm to turn quickly towards the centre of the road or to apply his brakes too suddenly. It is possible that the differential gear of the back axle plays some part in skidding under these circumstances. A reduced camber will produce a better and more even wear of the surface ; it will prevent traffic seeking the crown, and create safer conditions for all classes of traffic on the roads.

Cross-falls for Different Types of Paving.

Suitable cross-falls or cambers for various kinds of road surfaces but with some head-fall are given in the following table :—

Type of road.	Average cross-fall.
Water-bound macadam . .	1 in 24
Tar-macadam . . .	1 in 30
Bituminous macadam . .	1 in 36 to 1 in 48
Bituminous asphalte { concrete foundation }	1 in 48
Sett paving { concrete foundation } . .	1 in 48
Concrete paving	1 in 60 to 1 in 72

Where flat cambers are adopted and suitable head-fall exists,
the former barrel or parabolic shape (Fig. 13) may be dispensed
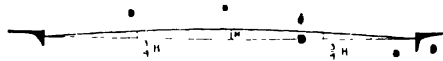
Fig. 13.—Typical Parabolic Section of Cambered
Road.

with and an even cross-fall to either side substituted, the
centre being rounded slightly, so as not to be discernible,
as shown in Fig. 14.

Fig. 14.—Reduced Camber suitable for Concrete
Roads.

Formula for Determining Crown Height.

Several rules or formulæ exist for the determination of the
crown height with regard to width and headfall.

Dare's formula is one which answers the purpose well for
ordinary sections :—

$$C = \frac{W(100 - 4L)}{6300 + 50L^2}$$

where   C = crown in inches.

W = width of road in inches.

L = longitudinal gradient per cent.

Clearly, the crown height is diminished as the longitudinal
gradient increases, but no consideration is given to the kind of
road surface.

Major F. S. Besson has suggested that the " three-quarter-
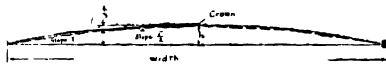
Fig. 14A.—Besson's Improved Section for Cambered
Roads.

height " in the parabolic crown section should be altered to a level
of ⅔ the crown height at the point half-way between the kerb and
centre of road (Fig. 14A) ; thus the gradient between this mid-

point and the channel is twice the gradient to the centre. The heights are joined with suitable arcs of circles. With this method the crown is slightly more pronounced, and the slope near to the channel is more acceptable for traffic than the steep slope of the parabolic section.

The following formulæ are suggested by Major Besson for the calculation of the cross gradients, T and $\dfrac{T}{2}$ per cent :—

$$T = 0.266(16 - L) \quad \dots\dots\dots\dots (1)$$

And for the calculation of crown height for city pavements :—

$$C = \dfrac{W}{10}(16 - L) \quad \dots\dots\dots\dots (2)$$

where   C = crown in $\dfrac{\text{feet}}{100}$, T = per cent crossfall grade.

W = width of roadway in feet.

L = longitudinal grade.

It will be clear that if L is constant for varying widths W, the value of T also is constant.

CHAPTER IV

CURVES

THE problem of suitable treatment for curves on the roads of this country has received scant consideration in the past. It must be admitted, however, that horse traffic, the speed of which was trifling compared with the modern motor vehicle, did not attract much attention to this now very important branch of road construction. Until recently it was unusual to find any increase of width at a bend in a road, and it is only with the development of fast-moving traffic that the urgency of wider carriageways and flatter curves at bends is fully realized.

The great length of the modern motor lorry demands greater width when turning, more particularly on the quick bends. There are many instances where bends could be eliminated by short cuts or by-pass roads, which would readily pay for themselves by reducing the area of road surface for maintenance, which is specially heavy at bends. In cases of this kind there should be no difficulty in arranging for such diversions now that the advice and financial assistance of the Ministry of Transport is available.

In the majority of cases where bends are concerned, widening can be effected by increasing the radius on the inside of the bend and, if possible, superelevation should be resorted to, or at least the widened portion should be lowered even if the crown remains unaltered.

There are several methods by which widening of this kind may be carried out, viz. :—

1. The simple curve.
2. The compound curve.
3. The spiral curve in use on railways.
4. The parabolic curve.
5. Bernouilli's lemniscate.

1. The Simple Curve.

In the simple curve method the inner side of the road is laid out with 'a larger radius' sufficient to give the extra width required. The setting out of each curve presents no practical difficulty ; either the method of offsets or deflection angles may be used for determining points on the curve. The general idea of this kind of widening is given in Fig. 15, which shows that the greatest width of road is midway of the bend.
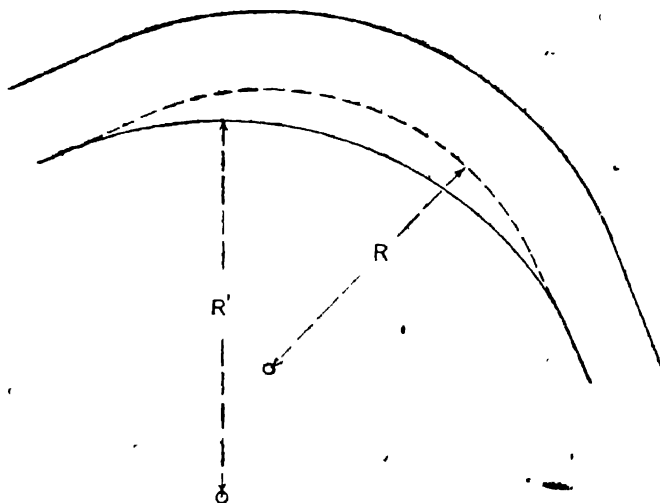
FIG. 15.—Widening Bend by Simple Curve.

2. Compounding Simple Curves.

There are objections to the simple curve for widening purposes, inasmuch as it may require a sharper deviation than is desirable and cause a greater width midway than is really necessary, thus rendering the outer portions of the road useless. The compound curve overcomes these difficulties. As will be seen by Fig. 16, the curve is compounded by two flat curves to the approaches from the straight, and a sharp or short radius curve to join the two curves midway on the bend. The range of vision is increased and vehicles of long wheel-base are able to pass without difficulty.

3. Spiral Curve.

The spiral curve takes the place of the flat curves in compound curve. It consists essentially of spiral approaches for transition from the straight to the simple curve. The curve is set out by offsets at intervals on the tangent lines on the inside of the road. This method is shown in Fig. 17 and has been largely adopted in America. The cubic parabola or cubic spiral is easily adapted for offsets ; in the cubic spiral the offset varies as the cube of the distance along the spiral.
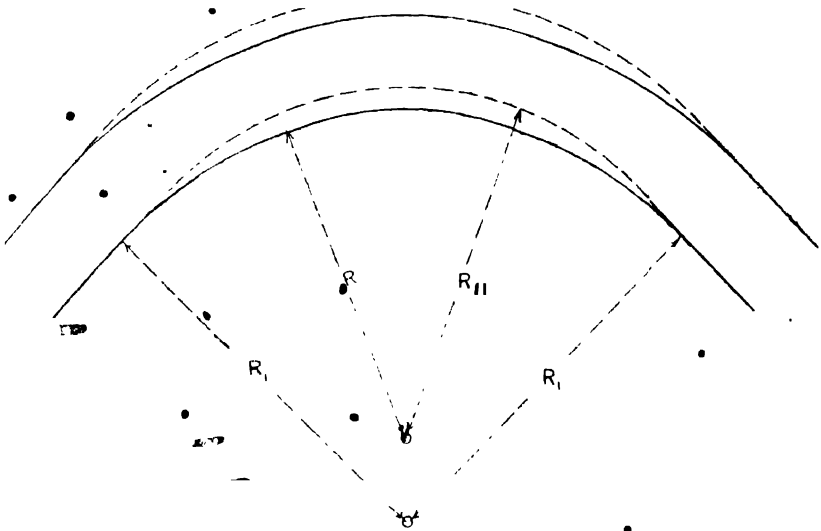
FIG. 16.—Improvement of Curve by Compounding Simple Curves.

4. Parabolic Curve.

The properties of the parabolic curve make it suitable for transition and widening purposes, and its adoption would certainly give general satisfaction to road users. As will be seen from the diagram in Fig. 18, the curve, which begins almost as a straight line, increases its curvature gradually to the middle point of the curve ; in other words, it provides its own transition, and the question of simple curves need not be considered. Taking a base line joining the two tangent points easy vertical
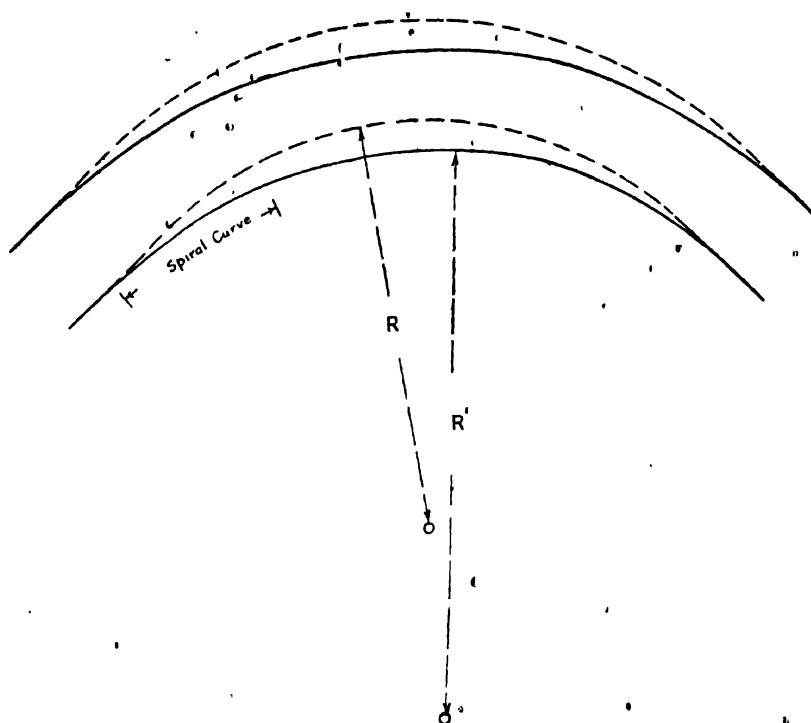
FIG. 17.—Improvement of Curve by Simple Curve and Spiral Approaches.
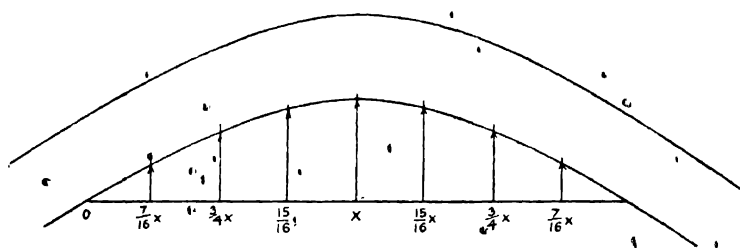
FIG. 18.—Use of Parabolic Curve for Improvement of Bends.

ordinates are readily erected by dividing the line into eight parts; the height of the second ordinate is ¾ of the middle ordinate. In order to obtain a greater width midway of the curve the inside curve may be a flatter parabola than the outside curve.

5. Bernouilli's Lemniscate.

This curve represents a French method of effecting the transition at bends or at the junction of roads in a progressive manner. It has some resemblance to the spiral transition and the parabolic curve, but if anything it is superior to both. A fundamental property of the lemniscate (Fig. 19) is that the
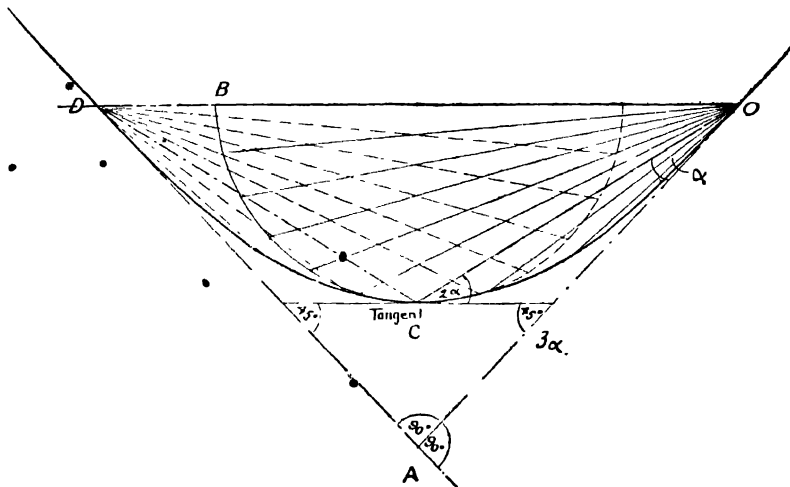
Fig. 19.—Bernouilli's Lemniscate for Road Curves.

tangent, at any point, makes an angle with the polar ray double the polar angle a, and it follows that the angle between the two tangents is equal to $3a$.

If ρ = the polar ray, a = the polar angle, and r = radius of circle at any particular point, and C a constant, the formula for the lemniscate may be written :—

$$\rho^2 = C^2 \sin 2a \dots\dots\dots\dots\dots\dots (1)$$
$$\rho = 3r \sin 2a \dots\dots\dots\dots\dots\dots (2)$$
$$\text{or } \rho = C \sqrt{\sin 2a}.$$

The limiting value for a is 45°, which is always the angle between the tangent line at origin OA and ρ when its value is a maximum as at OB (Fig. 19).

In this example the centre lines of the two roads to be connected are 90° and the lemniscate is drawn from O to C, which is part of curve OCB, and then repeated from D to C.

The length of OA is then decided upon, and of course this should be as great as practicable. The angle a is clearly $\dfrac{45°}{3} = 15°$.
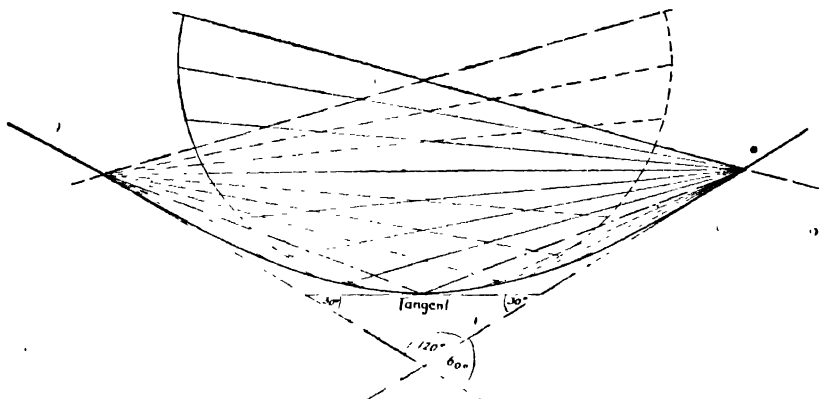
Fig. 19A.—Bernouilli's Lemniscate for Road Curves (Obtuse Angle).

The length of the polar ray for $a = 15°$ may be determined by calculation for one side of triangle OCA, or by geometrical construction by drawing from O and from D to intersect at C.

Knowing the value of ρ for a given value of a the constant C may be determined :

$$C = \frac{\rho}{\sqrt{\sin 30°}}.$$

This gives the value of C, and enables all polar rays for the curve OCB to be calculated.

If now the theodolite is set up at O the various polar ray lengths for different angles and the points on the curve may be defined between O and C. This procedure is repeated at D and curve DC defined from the same dimensions ; alternatively the curve may be set out by offsets.

This curve is eminently suited to the natural path of a motor vehicle when negotiating a bend.

Another example of this method of intersecting the lemniscates is shown in Fig. 19A, where the angle between the tangents is 30° and a is 10°, whilst the interior angle of intersection of the centre lines of road to be connected is 120°.
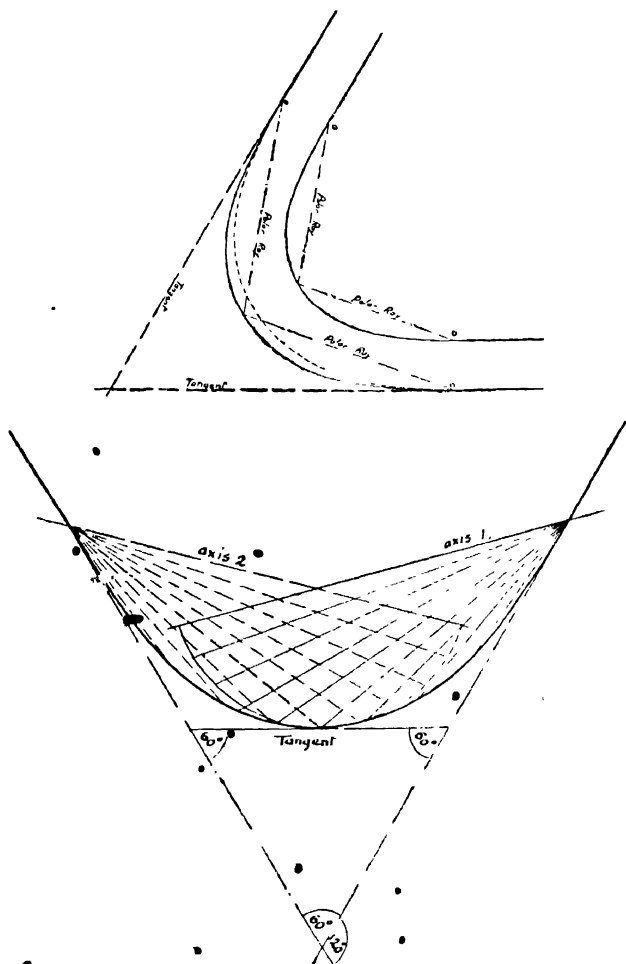
FIG. 19B.—Bernouilli's Lemniscate for Road Curves (Acute Angle). Showing Natural Widening.

To use the lemniscate for transition to a main curve of, say, 200 ft. radius we have from (2) $\sin 2a = \dfrac{\rho}{3r}$.

If the length of transition is 50 ft., i.e. in order to apply the maximum superelevation, then $\rho = 50$ ft.,

$$\text{and } \sin 2a \quad \frac{50}{600} = \frac{1}{12} \text{ or } \cdot 0833$$
$$2a \quad 4° 40'$$
$$a = 2° 20'$$

which is the polar angle for $\rho = 50$ ft. and is the point of commencement PC of the main curve. Where the lemniscate is used more fully, it is a good plan to set out the kerb lines independently, as this gives a gradual widening to a maximum at the mid-point of the bend and at the point of greatest curvature.

This is shown clearly in Fig. 19B, where two roads intersecting at an acute angle are connected by lemniscate curves.
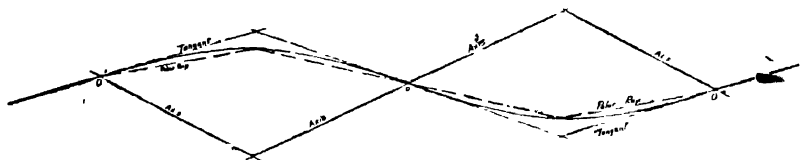
FIG. 19c.—Bernouilli's Lemniscate for Serpentine or "S" Curves.

Another useful application of this curve is for serpentine curves. The advantage in this case lies in the short straight length in the vicinity of point O, and the gradual deviation therefrom, although there is nothing to prevent the change of direction being made with a greater straight section between the curves to facilitate the change from superelevated to crowned section. The example shown (Fig. 19c), however, enables the banking to be performed with perfect safety.

Tables of offsets or polar co-ordinates may easily be prepared for main curves of varying radii.

The following table shows the values of $\sin 2a$ for values between O and 45° :—

Values of sin 2α and $\sqrt{\sin 2\alpha}$ for $p=c\sqrt{\sin 2\alpha}$ and $3r\sin 2\alpha$.

α	sin 2α	$\sqrt{\sin 2\alpha}$	q	sin 2α	$\sqrt{\sin 2\alpha}$	α	sin 2α	$\sqrt{\sin 2\alpha}$
44°	·9993	·9997	29°	·8480	·9208	14°	·4694	·6851
43°	·9975	·9988	28°	·8290	·9105	13°	·4383	·6621
42°	·9945	·9972	27°	·8090	·8995	12°	·4067	·6377
41°	·9902	·9952	26°	·7880	·8878	11°	·3746	·6120
40°	·9848	·9924	25°	·7660	·8752	10°	·3420	·5848
39°	·9781	·9891	24°	·7431	·8621	9°	·3090	·5559
38°	·9702	·9851	23°	·7193	·8481	8°	·2756	·5250
37°	·9612	·9804	22°	·6946	·8334	7°	·2419	·4919
36°	·9510	·9752	21°	·6691	·8180	6°	·2079	·4560
35°	·9396	·9694	20°	·6427	·8017	5°	·1736	·4166
34°	·9271	·9629	19°	·6156	·7846	4°	·1391	·3730
33°	·9135	·9559	18°	·5877	·7666	3°	·1045	·3233
32°	·8987	·9479	17°	·5591	·7477	2°	·0697	·2640
31°	·8829	·9397	16°	·5299	·7279	1°	·0348	·1866
30°	·8660	·9307	15°	·5000	·7071			

There is little doubt that the employment of superior curves for transition between the straight line and the circle will bring about an economy both in construction and maintenance of considerable value.

The question arises as to how far the transition curves should be adopted for the outside curves at bends, and here again the matter of economy comes in. If it is left as a simple curve it is certain that the tendency of motor traffic will be to travel towards the inner side of the road, especially about midway on the curve, and the outer strip will be more or less useless. The adoption of easements or transition curves (e.g. the lemniscate) on the outside similar to those on the inside is therefore an advantage in many cases, although on existing roads the cost of alteration may perhaps be avoided.

Need for Increased Width on Curves.

It is highly important, however, to have a definite increased width on the quick bends where inner and outer transition is effected.

The extra width required by motor vehicles may be determined in the following manner :—

In Fig. 20 let R = the radius to the outer front wheel, i.e. the radius of the curve, and r, the radius of the curve traversed by the inner rear wheel. Let $l =$ wheel base and w the width between rear wheels. If the arc of radius R is made to cut the line passing through the rear axle in point F, then FA represents the extra width required in turning.

$$\text{Then } R - (r + w) = FA.$$
$$\text{But } (r + w) \qquad = \sqrt{R^2 - l^2}.$$
$$FA \qquad\qquad = R - \sqrt{R^2 - l^2}.$$

This value should be doubled in ordinary cases to allow of vehicles passing in each direction. The following table represents the amount of extra width for different radius turns, taking motor lorries of 16 ft. wheel base. In addition to the calculated width it is advisable to increase this to allow a greater margin for clearance in negotiating such bends.

Radius at centre line.	Extra width for one vehicle.	Extra width for two vehicles.	Suggested extra width to allow for turning with two lines of traffic.
25 ft.	4·7 ft.	9·4 ft.	12 ft.
50 ft.	2·5 ft.	5·0 ft.	8 ft.
75 ft.	1·65 ft.	3·3 ft.	6 ft.
100 ft.	1·3 ft.	2·6 ft.	5 ft.
125 ft.	1·0 ft.	2·0 ft.	4 ft.
150 ft.	·8 ft.	1·6 ft.	3 ft.
200 ft.	·5 ft.	1·0 ft.	3 ft.

Taking $l =$ the wheel base $= 16$ ft.

Hairpin Curves.

These dangerous points on the highway usually occur on steep hills, and should only be tolerated where there is no other solution ; they are dealt with in the chapter on " Hill Roads."

Curves for Right-angled Intersections.

Where two important roads meet or intersect at right angles it is advantageous to introduce curves of as large a radius as

possible. If one or both roads are narrow, a wide mouth or
entrance from one to the other is a precaution in the interests of
public safety. In country areas this improvement can usually be
effected without much difficulty, but in towns existing buildings
frequently complicate matters by obstructing the view and
preventing an improvement on account of the great expense
involved. In such cases for any degree of safety low speeds are
a necessity.
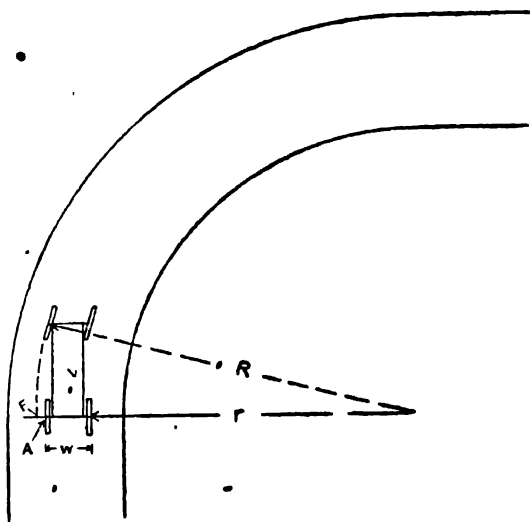
Fig. 20.—Diagram showing the Extra Width Required at
Bends.

Road Mirrors for Blind Turnings.

This device is usually placed at an angle, so that traffic going
along either road and approaching the corner can see the traffic
on the other. The idea of the mirror is certainly sound, as it
gives warning from one road to the other. There are only a few
cases in this country where mirrors are installed—generally at
intersections of narrow congested thoroughfares in towns. It is
hardly likely that this simple apparatus will be adopted to any
great extent, despite its obvious advantages. Its usefulness
depends largely upon force of habit; a stranger, for instance,

R.E.—D

would probably miss seeing the mirror, or if unacquainted with it, he might, at first glance, think he was about to run into a vehicle in the vicinity of the reflector, especially during darkness. The mirror may be oblong in shape and should be sufficiently high to be useful to drivers at different elevations. Fig. 21 shows an arrangement for a double mirror to assist traffic passing out of a concealed turning into a main road.
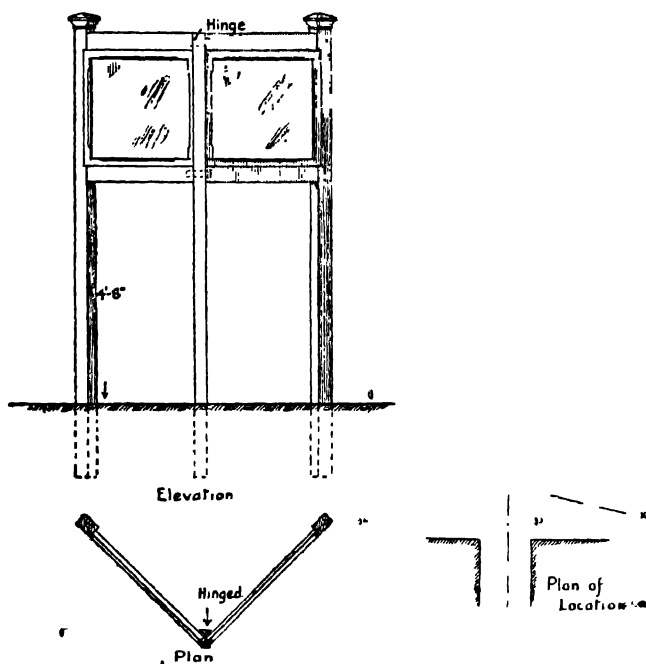
FIG. 21.—Double Road Mirror for Concealed Turning.

Range of Vision.

The question of curvature is obviously closely bound up with that of range of vision for drivers. A sharp curve—giving as it does a shorter range of vision—produces slower average speeds, whereas a flat curve with a high range of vision permits of higher speeds.

Mr. A. R. B. Armstrong, Assoc.M.Inst.C.E., of the Indian

P.W.D., gives the following formula for relating speed to range of vision :—

$$(\text{Speed in m.p.h.})^2 = 2 \times (\text{limit of view in feet}).$$

In order to obtain the length of clear view along the centre line of the road it is necessary to know the radius of curvature, the half-width of road and the additional width due to set back of hedge or slope of hill.

The whole question of curvature at bends is intimately connected with superelevation, and this is fully treated of in the next chapter.

Note.—See Clark's " Plane and Geodetic Surveying " (Vol. I, Glasgow C.E. Series) for further information *re* transition curves and general setting out.

CHAPTER· V

SUPERELEVATION on curves has hitherto been confined to railway design. In the days when the roads were dedicated to horse·traffic the need for banking up the outer portion of a curve was never considered, and the cambered section was the rule rather than the exception.

In 1920 the Author called the attention of the Roads Improvement Association to the necessity for superelevation at bends ; the matter was pursued and a request made to the Ministry of Transport, asking them to issue a circular dealing with it. The request was supported by details of superelevation practice in America and France, together with the opinion of several leading British road engineers. The result of this application was that the Ministry issued instructions to its divisional engineers to the effect that superelevation should be introduced where desirable in all improvement schemes. The principle' therefore is accepted by the Ministry, and it is to be hoped that in future the fact that a bend is cambered and·badly worn would be sufficient for it to rank as a grant-earning road improvement.

The disadvantages of the cambered section of the road surface at bends may be stated under the following headings :—

(a) Excessive Wear.

There is no part of a road surface which fails so quickly as that of bends. This is due to the action of centrifugal force, which produces unequal pressure on the wheels, thus causing vibrations and consequent damage to the wearing surfaces usually in the form of waves or potholes.

(b) Danger of Skidding and Colliding.

The possibilities of accidents occurring at a sharp bend are fairly apparent to most users and observers of road surfaces. The natural tendency of all modern motor traffic, whatever its direction, is to cut in on the inside of the turn in order to obtain assistance from the banking effect of the inner camber. This is really what occurs in practice, and under these conditions the outer half of the road is hardly subjected to wear at all. The result is that there is a serious danger of collision occurring on cambered sections ; any sudden change of direction or the application of the brakes will cause the vehicle to skid, owing to the uneven pressure on the rear wheels and the uneven wavy road surface. Moreover, tyres are more easily torn or burst from the rim when rounding bends. Many accidents have been recorded under these circumstances.

(c) Danger to Vehicles Travelling on the Outside Bend.

Occasionally it happens that a vehicle is compelled to travel on the outside bend owing to inner slope being in use by traffic going in the opposite direction. The effect of the outer slope combined with the turning of the vehicle itself may result in a strong overturning or skidding tendency. This is also a constant source of accidents.

(d) Effective Width Reduced.

On the sharper curves, the outer portion of the road being little used, the remainder of road surface is correspondingly crowded and the traffic concentrated. This leads to tracking or wearing definite tracks with disastrous results. Many drivers are quite unaware of the amount of extra width required in steering round a curve, the crowding of traffic at which is therefore undesirable.

It is true that the principle of banking has long been in use in this country for cycle and motor racing tracks, as at Brooklands, New Brighton, etc., and it is all the more extraordinary that there has been no serious attempt to embody it in road construction—at any rate, on first-class roads—until recently.

Coefficient of Friction

Before entering into the mechanics of the question it is advisable to refer to some tests on skidding and the coefficient of friction, which have been carried out by the Indian P.W.D. A Thornycroft and a Leyland lorry were employed for the purpose, and with an initial speed of 15 miles per hour the vehicles were brought to a standstill in the following distances :—

Thornycroft lorry in 25 yd. on a dry road . . . (1).
Thornycroft lorry in 50 yd. on a greasy road . . . (2).
Leyland lorry in 15 yd. on a dry road . . . (3).
Leyland lorry in 50 yd. on a greasy road . . . (4).

In each case the kinetic energy at the start =

$$\frac{Wv^2}{2g} = \frac{W \times 22^2}{2 \times 32 \cdot 2} = 7 \cdot 5W.$$

In (1) $7 \cdot 5W$ was destroyed in 75 ft. and therefore the retarding force is :—

$$\frac{\text{Momentum}}{\text{Distance}} = \frac{7 \cdot 5W}{75} = \frac{W}{10}.$$

The frictional resistance is effected by brakes on the rear wheels only, the front wheels being quite free. Assuming that $\frac{2}{3}$ of the weight comes on the rear axle of the vehicle, which ratio is fairly correct for practical purposes, the coefficient of friction for (1) is therefore $\frac{1}{10} \times \frac{3}{2} = 0 \cdot 15$. Similarly the other values are (2) $0 \cdot 08$, (3) $0 \cdot 25$, and (4) $0 \cdot 08$.

Other observations in connection with these investigations show that at speeds of about 17 m.p.h. skidding was noticed on curves of 25–75 ft. radius banked at 1 in 12. The critical speed on a 25–45-ft. radius curve is considered to be 15 m.p.h.

The analysis of superelevation consists in determining the amount by which the outer edge of the road at a curve must be raised above the inner edge in order to counteract, through the wheels at the road surface, the centrifugal force acting on the vehicle according to its speed and the radius of curvature. The effect of this tilting or crossfall is to move the centre of gravity

inwards sufficiently to balance the outward effect of the centrifugal force.

In Fig. 22 if W = the weight in lb. of the vehicle and R the radius of the curve (in ft.) the centrifugal force $CF = \dfrac{Wv^2}{gR}$ where v = the velocity in ft. per sec. and g = 32·16 ft. per sec. The three forces W, R, and CF intersect in one point being in equilibrium, and the triangle of forces is readily constructed.
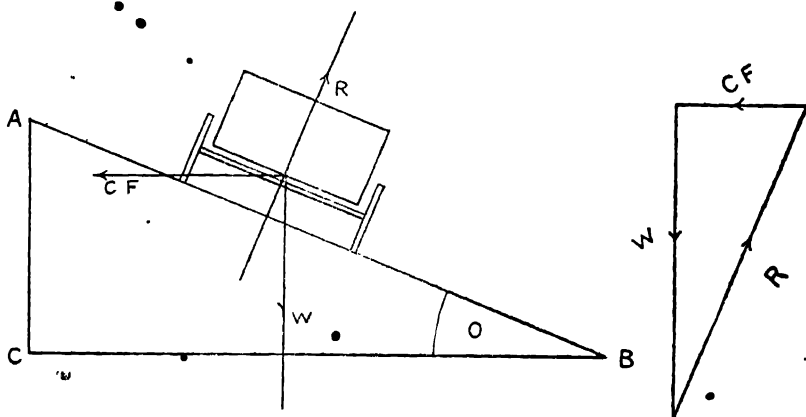
FIG. 22.—Diagram showing the Relation of Forces for Superelevation on Curves.

Considering the triangles ABC and W–R–CF and the triangle of forces which are similar, we have—

$$\frac{CF}{W} = \frac{AC}{CB}, \text{ but } CF = \frac{Wv^2}{gr}.$$

$$\therefore \quad AC = \frac{Wv^2}{gr} \times \frac{CB}{W} = \frac{CB \times v^2}{gr}.$$

By substituting unity for CB, 32·16 ft. per sec. per sec for g and m.p.h. for V, the superelevation per ft. width of road is obtained, viz :—

$$AC = \frac{V^2}{15r} \text{ (nearly)} \dots \tag{1}$$

Assuming a speed of 20 m.p.h. on a curve of radius 100 ft.,

this would give a value for superelevation of 0·26 ft. per ft. width, or roughly 1 in 4. It is obvious that this value is far in excess of a safe cross-fall to accommodate all kinds of traffic and tyres under varying speeds. With a larger radius greater speeds are usual and the calculated cross-fall may be about the same, viz. 1 in 4 or 5. It is the engineer's duty, therefore, to reduce this calculated value for banking to a figure which will produce conditions of safety both for slow and fast traffic. Generally the rate of superelevation should not exceed 1 in 10 and, indeed, it has been argued that this is excessive for iron tyres and

Speed in Miles per Hour.

FIG. 23.—Graph showing the Relation of Speed and Curvature for Complete Superelevation.

horse traffic. The condition of the road surface has much to do with this objection, and there is little evidence to show that iron-tyred wheels would skid to the inside edge either when standing still or moving. This cross-fall, i.e. 1 in 10, is sufficient to provide a reaction which will balance substantially the centrifugal force of vehicles at 20 to 30 m.p.h. on curves of radius of 100 to 200 ft.; the remainder must come from the friction of the tyres themselves at the road surface. The least radius of curvature for a speed allowance of 25 m.p.h. at 1 in 10 to produce no side thrust on the road is about 415 ft., and for a speed allowance of 20 m.p.h. is 267 ft.

It should be mentioned here that there is a strong element of prejudice still in existence against the adoption of superelevation in this country. This arises from the belief that banking will encourage racing and an increase of speed generally, which is largely an argument built upon imagination, and probably arising from the recollection of well-banked racing tracks. Having regard, however, to the fact that the permissible allowance for superelevation can only partially accom-

modate side thrust, there is no cause for alarm in such proposals.

The following table and also the graph in Fig. 23 indicate the least radius of curvature which would give complete protection to traffic, or full banking effect with no side thrust on the road surface at different speeds:—

VALUES OF RADIUS OF CURVATURE FOR COMPLETE BANKING EFFECT

Speed value	1 in 10 or 1.2 in. to 1 ft	1 in 12 or 1 in. to 1 ft.	1 in 16 or ¾ in. to 1 ft.	1 in 24 or ½ in. to 1 ft.
15 m.p.h.	150 ft.	180 ft.	240 ft.	360 ft.
20 m.p.h.	267 ft.	320 ft.	427 ft.	640 ft.
25 m.p.h.	415 ft.	500 ft.	667 ft.	1000 ft.
30 m.p.h.	600 ft.	720 ft.	960 ft.	1440 ft.

Conditions where Level or Insufficiently Superelevated.

Where road curves are not superelevated the limiting conditions of equilibrium of a vehicle passing round the curve will be
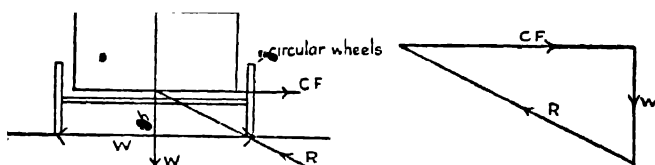
FIG. 24.—Diagram showing the Relation of Forces on Vehicle on Curves not Superelevated.

when the inner wheel is taking no load, and the reaction acting from the outer wheel passes through the centre of gravity as in Fig. 24. The centrifugal force will be the same as the horizontal frictional force acting at the wheel tyre ; and the overturning moment will just be balanced by the righting moment.

Centrifugal force $= \dfrac{W v^2}{g r}$.

Let h = height of centre of gravity and w = gauge of wheels,

Then $\dfrac{Wv^2}{gr} \times h = W \times \dfrac{w}{2}.$

But $\dfrac{Wv^2}{gr} \times \dfrac{1}{W} = \dfrac{v^2}{gr} = \mu$, coefficient of friction.

Now if we take μ as being equal to 0·25, the centrifugal force must be equal to $\frac{1}{4}$ the normal pressure of the vehicle—in this case $= W$. It is clear, therefore, that in order to overturn, the height h of the centre of gravity must exceed twice the gauge of the wheels, that is to say, $CF \times 2w > W \times \dfrac{w}{2}$; but the height
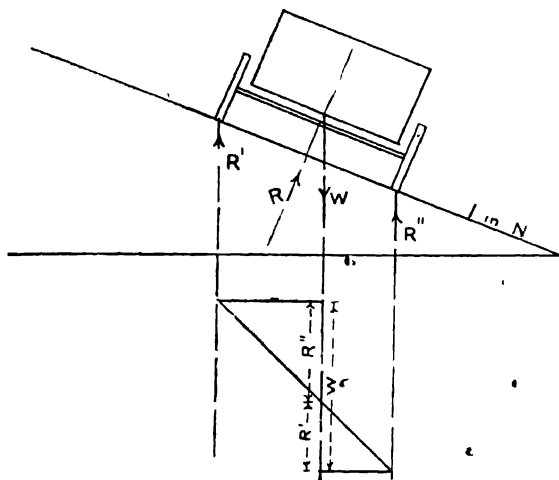
Fig. 25.—Diagram showing Relation of Forces on Standing Vehicle on Superelevated Curve.

of the centre of gravity is usually much less than w, and therefore it is almost impossible for a motor bus to overturn when rounding a bend, because skidding would occur in the first place to prevent it : e.g. :—

If $h = w$, then $CF \times w = W \times \dfrac{w}{2}.$

$\therefore \dfrac{CF}{W} = 0·5 = \mu$, the coefficient of friction.

But even under rough conditions of surface, and with the best

non-skid tyres, it cannot be conceived that the value of μ would ever approach 0·5, and skidding would occur before overturning could take place.

In the case of a road where the surface is insufficiently banked to prevent side thrust or friction at the point of contact with the wheels, the various forces may be determined graphically in the manner shown in Fig. 22. Knowing the speed and weight of the vehicle and also the radius of curvature of the road, the value of the centrifugal force is readily calculated. Then by the principle of the triangle of forces, the three forces acting on the vehicle must now pass through the one point, viz. the centre of gravity for conditions of equilibrium; the magnitude and direction of the total reaction from the road are then found in the usual way.

The coefficient of friction at each wheel contact is approximately the same, although the wheel loads are different, and the value and direction of the reactions at the wheels may be obtained by first resolving the total reaction R, graphically, as shown in Fig. 25.

FIG. 26.—Diagram showing the Relation between Frictional Force, Superelevation, Curvature, and Speed.

The values of R′ and R″ are easily resolved into the normal and frictional forces by parallelogram of forces.

The problem may be further considered graphically as follows :

Let   1 in N = rate of banking.

Then $\tan \theta = \dfrac{1}{N}$

and $\cos (\theta + \phi) = \dfrac{F}{R} = \mu$,

the resultant R of the forces W and centrifugal force CF shown in Fig. 26 found by parallelogram of forces, and afterwards resolved into a normal force N and F.

Then $\frac{CF}{W} = \frac{v^2}{gr} = \cot \phi$.

Taking the limiting value of μ at 0·25 for average conditions we can readily determine the safe speeds round bends according to the radius of curvature and slope of banking.

An example is given here to indicate the application of this formula :— Let $r = 300$ ft. radius and rate of banking 1 in 12.

Then $\tan \theta = \frac{1}{12} = 0·0833$.

and $\theta = 4° 45'$.

Now $\cos (\theta + \varphi) = \frac{F}{R} = 0·25$.

$\therefore \quad \theta + \varphi = 75° 29'$

and $\varphi = 75° 29' - 4° 45' = 70° 44'$.

In triangle AEF,

$\frac{W}{CF} = \tan \varphi = \frac{gr}{v^2}$.

Fig. 27.—Graph showing the Relation between Curvature, Rate of Banking, and Safe Speed.

$$\therefore \quad v = \sqrt{\frac{gr}{\tan \varphi}} = \sqrt{\frac{32 \times 300}{2 \cdot 861}} = \sqrt{3355} = 58 \text{ ft. per sec.}$$
$$= 40 \text{ miles per hour approx.}$$

The safe speeds for various slopes of banking and various curvature are shown in the following table and graph in Fig. 27.

TABLE SHOWING *Safe Speeds* FOR VARIOUS CURVATURES AND SLOPES
OF BANKING FOR COEFFICIENT OF FRICTION $\mu = 0.25$

Rate of banking.	Radius of curvature in feet.							
	25	50	75	100	125	150	175	200
	V. Miles per hour.	V. Miles per hour.	V. Miles per hour.	V. Miles per hour.	V. Miles per hour.	V. Miles per hour.	V. Miles per hour.	V. Miles per hour.
1 in 5	13·6	19	23·2	36·9	30	32·7	38·2	42·6
1 in 8	12·2	17	21·1	24·2	27·3	29·6	34	38·2
1 in 10	11·8	16·7	20·4	23·6	26·4	28·8	33·4	37·2
1 in 12	11·6	16·3	19·8	22·8	25·6	27·9	32·4	36·1
1 in 16	10·9	15·7	19	21·8	24·5	26·9	31	34·7
1 in 24	10·5	15	18·4	21·1	23·8	25·9	30	33·7

The ratio of centrifugal force to weight of vehicle at different curvature and speeds on level cross sections, i.e. without super-
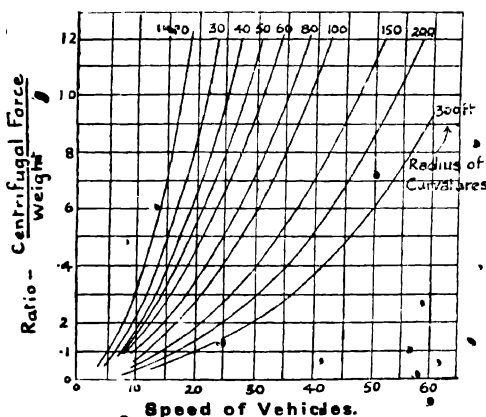
FIG. 28.—Graph showing $\dfrac{\text{Centrifugal Force}}{\text{Weight}}$ Ratio to
Speed for Various Curvatures.

elevation, is of interest, as this represents the coefficient of friction; this is shown in the graph, Fig. 28.

, The Methods of Effecting Superelevation.

Generally the section of the road to be dealt with is cambered, and it is necessary for this slope to be changed gradually to a continuous slope from outer to inner edge of the curve. The change may be accomplished by revolving the surface either about the axis of its centre line or about the inner edge of the pavement as an axis, as shown in Fig. 29.

It will be readily conceded that the more desirable of these two methods is the former, because there is no hump or break in the longitudinal gradient as is the case with the latter. However, the
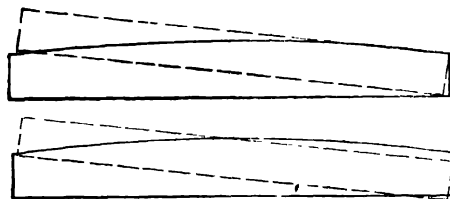
Fig. 29.—Methods of Effecting Superelevation (1) by Rotation about the Centre Line; and (2) by Rotation about the Inner Edge.

hump caused in this manner is only slight, since the inner half is already sloped to the inner edge on the cambered section, and in any event it occurs on a curve and would therefore be unnoticeable; there is one objection, however, and that is the outer edge is raised more than by the other method, and this usually necessitates more filling, especially for steep banking.

A superelevation rate of 1 in 24 would mean in practice the extension of the inner slope of the cambered section.

The question naturally arises as to the point on the curve at which superelevation should commence. No superelevation should be introduced unless one or other of the transition curves is applied at or near the departure from the straight, and the width of the road should be increased on the bend itself.

This enables the superelevation to be increased gradually until the maximum cross-fall allowed occurs at the end of the tran-

sitions. It must not be forgotten that one of the objects of banking a road is to induce vehicles taking a right-hand turning (British rule of the road) to travel on the outer side of the road, and the method of the elimination of the crown may have the effect of driving vehicles to cut in on the inside. The success of this has a most important bearing on the comfort of the road user.

The transition curve should be sufficiently long to enable these changes to be made : about half of this length will be required to eliminate the crown. The point of commencement of the transition curve should be flat if possible. A typical example of a spiral transition curve is shown in Fig. 30, and an illustration of a transition curve set out by offsets at 10-ft. intervals and meeting a simple curve is shown in Fig. 31.

In the former case half of the superelevation has been applied in a length of 60 ft.

With a superelevation of 1 in 10 and a road width of 30 ft. this would raise the outer edge at P.C. $\frac{1}{20} \times \frac{15'}{1}$, or 9 in. above the centre line. Assuming that the channel at the normal section is 4 in. below the crown the maximum gradient due to change of section would be 1 ft. 1 in. in 60 ft., or approximately 1 in 55.

As a matter of fact, for traffic purposes the gradient would be much less, and only in the exceptional case of a vehicle keeping close to the side would this gradient happen.

As a general rule, however, a longitudinal change of a gradient of 1 in 50 is very suitable for a smooth change of section at speeds of 25 m.p.h. If high speeds are anticipated then this gradient should be flattened ; in other words, the length of transition should be increased.

An example of application of the lemniscate for superelevation is given in the previous chapter. Where, however, the lemniscate is employed for the whole curve the superelevation is calculated for the minimum radius of curvature, i.e. at the midpoint of the curve; from this point the superelevation in Fig. 19 will diminish in each direction, and this should be as gradual as possible. If calculated at different points, the superelevation and

Fig. 30.—Example of Spiral Transition Curve with
Superelevation.

the curve itself will give practically perfect conditions for negotiating the bend.

Short sharp curves may require a high rate of banking, and in such cases it may be necessary to commence the application of super-elevation on the straight lengths. This presents no practical difficulty, as it is similar to the practice, alluded to elsewhere, of adopting cross-fall from one side to the other instead of camber.

American Practice in Superelevation

The practice in America seems to vary in the different States with regard to the amount of superelevation, the transition curves, and the increase of width. The American Committee on "recommended practices for concrete roads and street construction" has recommended a maximum superelevation of $\frac{3}{4}$ in. per ft. of width on curves having a radius of 150 ft. or less : for complete superelevation this will give a speed of about 12 m.p.h. at 150 ft. radius. On curves having a radius of 150 ft. to 500 ft. the
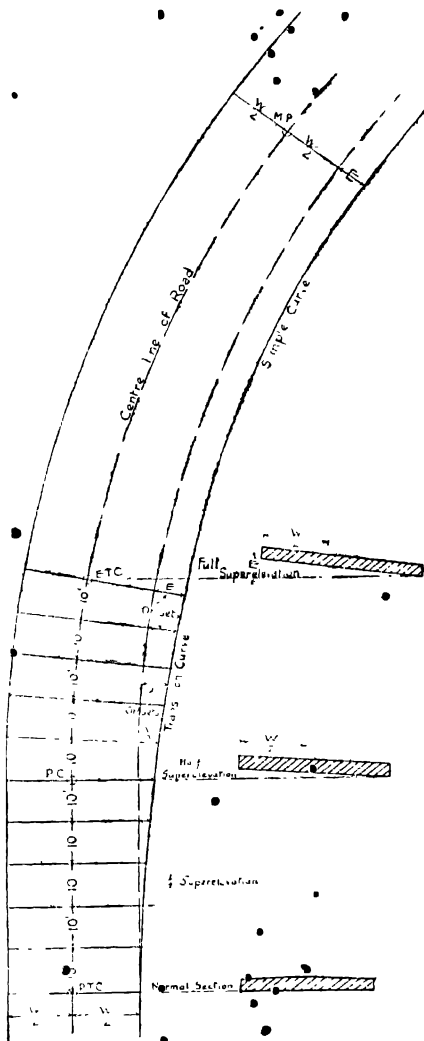
Fig. 31.—Example of Transition Curve (by Offsets) and Simple Curve, with Superelevation.

R.E.— E

rate of slope recommended is $\frac{1}{8}$ in. per ft., and over 500-ft. radius curves the normal crown is recommended. At 200 ft. radius, this provides for a speed of 11 m.p.h., and at 500 ft. for 17 m.p.h., and so it is 'necessary to recognize that these rates of slope only provide part of the resistance to centrifugal force at the average speed of vehicles, the remainder being taken up at the wheel contacts with the road surface. It was clearly the object of this committee to provide only partial banking in order not to induce traffic to indulge in high speeds.

Most of the States seem to have in operation different rates of slopes from the above-mentioned, but none of them provide complete superelevation, nor do they provide transition curves for the outer edge of the bend, and some of them attempt transition with an inside curve of greater radius. The present practice generally provides for the elimination of the crown section between the point of commencement of transition and the end where the principal curve begins.

In New York State the standard is a 300-ft. maximum radius of curvature and superelevation to compensate for a speed of 20 m.p.h. with an increasing amount of compensation for curves of longer radius where the limit of vision is greater.

The table on next page will indicate clearly recent practice in various States.

In each case the pavement cross-section is of uniform slope and thickness, and the curves generally of uniform width; also the road is revolved on the centre line as an axis. In rural areas, where no kerbs exist, it is desirable to place a kerb or edging on the inner edge of the road at the bend to act as a toe to take the thrust from the banked highway.

French Practice

Recent practice in France and Morocco indicates that super-elevation for road bends is a definite policy in road constiuction. The Touring Club of France in 1905 made the following recommendations :—

Radius of curvature.			Rate of banking.
30 metres	.	. .	3%
40 metres	.	. .	5%
50 metres	.	. .	6%

State.	Pitch of fully superelevated sections.		Transition section and rate.
	Pitch per feet of width.	Radius.	
California Mountain Roads.	$\frac{3}{4}''$ per ft. $\frac{3}{8}''$,, $\frac{1}{8}''$,,	up to 75' 100' to 150' 225' to 300'	Length, 30' 0''; 15' on curve, and 15' on tangent.
Indiana	$\frac{1}{2}''$ per ft.	All curves	Length 100'. Full superelevation at principal curve (P.C.).
Michigan	1'' per ft. $\frac{3}{4}''$,, $\frac{5}{8}''$,, $\frac{1}{2}''$,,	66' to 150' 150' to 300' 300' to 450' 450' to 700'	Length, 100'; 75' before P.C. to 25' past to reach full superelevation.
New Jersey	$\frac{1}{3}''$ per ft.	All curves	Length, 100'. Full superelevation at principal curve.
New York	1'' per ft. $\frac{3}{4}''$,, $\frac{1}{2}''$,,	up to 300' 800' to 1500' 1500' to 2500'	Length or transition varying from 85' to 35' before P.C.
Ohio	$\frac{1}{2}''$ per ft. to $\frac{1}{8}''$ per ft.	900' to 1400' 5000'	Length, 100' from 50' before to 50' past P.C.
Pennsylvania	$\frac{1}{2}''$ per ft.	50' to 300'	Spiral transition on inside curve according to special table.
Washington	$\frac{5}{8}''$ per ft. to 0·22'' per ft.	190' 5000'	Same as Ohio.
West Virginia	1'' per ft. 0·3'' ,,	75' 400'	Length, 75'; $\frac{1}{3}$ superelevation at P.C. and $\frac{2}{3}$ at 25' past P.C.

These values show that the superelevation is now very far short of that required to accommodate motor vehicles at average speeds. The speed which has been accepted recently as an average for all vehicles is about 40 to 45 kilometres p.h.

The following figures are now proposed as a safe medium to adopt on any bend :—

Radius of curvature.		Speed.		Inclination.
Metres.	Feet.	K. per hour.	Miles per hour.	
30	98	20	12·4	10%
40	131	30	18·6	} 20%
56	183	35	21·7	

It is also suggested that superelevation should be confined to touring roads for the present.

As a means for catering for horse traffic the method adopted in Morocco on the Meknés road is worthy of notice. This road is an
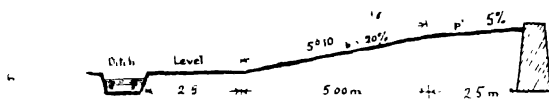
Fig. 32.—Superelevation on the Salé to Meknés Road, Morocco.

important thoroughfare in the new network of roads recently built by the French Government for the development of this fertile country. The rate of superelevation, as shown in Fig. 32, is 1 in 5—a value very much in excess of anything likely to be adopted in this country. At the lower edge of the banking the road is practically flat for a width of 2·5 metres, whilst the outer part of the curve, also 2·5 metres wide, has a slope of 1 in 20. This section enables the slow traffic to travel at either side with safety, and the fast traffic to benefit from the superelevation of the middle portion of the road.

Obviously a vehicle which has one wheel on the flat and one wheel on the centre portion of the road will have a less inclination to the vertical than when both wheels are on the fully banked

road section. This fact leads one to the conclusion that under some conditions a cross-section having broken superelevation would meet the requirements of all traffic using the road.

General Practice

In view, however, of the adoption by the Ministry of Transport of the principle of superelevation it may not be inopportune to state some of the difficulties encountered and the precautions necessary in carrying out superelevation. *The success of superelevation depends largely upon the care exercised in setting out and working to levels,* and an engineer should be constantly in attendance during construction. It is most desirable to have superelevated curves on the whole of the main route rather than to have only part of the route superelevated. As previously mentioned, the greatest difficulties in constructing curves of this kind occur when the change from crowned to superelevated surface takes place. This change must be very gradual or else, apart from the discomfort to the road user, vibration of traffic will be set up, which will in turn cause corrugation. This will depend to some extent upon the speed of the vehicle, and, so long as the rate of banking accommodates the traffic, even only partially, this danger is relatively small. The greater the accuracy and care bestowed on the levels the less will be the subsequent wear on the surface.

Setting Out.

The setting out of levels for the formation of the superelevated surface is done by means of pegs fixed at the side of the road. These should be spaced at about 10-ft. intervals for use with straight-edges (see Fig. 31). It is important to note the longitudinal gradient of the road along its centre line.

In the case of macadam or bituminous macadam roads, where rolling has to be adopted, the procedure is somewhat different from that employed for roads with concrete surface or foundation. Generally the amount of metal can be spread with sufficient accuracy to ensure a correct surface when rolled : the roadmen will require to know approximately the ratio of thickness before and after rolling. Rolling may produce initial waves, but these

may be practically eliminated if some diagonal rolling be resorted to. It is of the highest importance that there should be no initial waves because of the increased corrugating tendency of all traffic at bends.

Superelevation for concrete, sheet asphalte, or sett paving is much more easy of accomplishment ; indeed concrete, either as a foundation or a surface, is most desirable for all bends. Forms are set up at the inside and outside edges to the necessary levels and gradients, and the concrete is worked to those levels

Section A B

BEND IN ROAD ON LEVEL
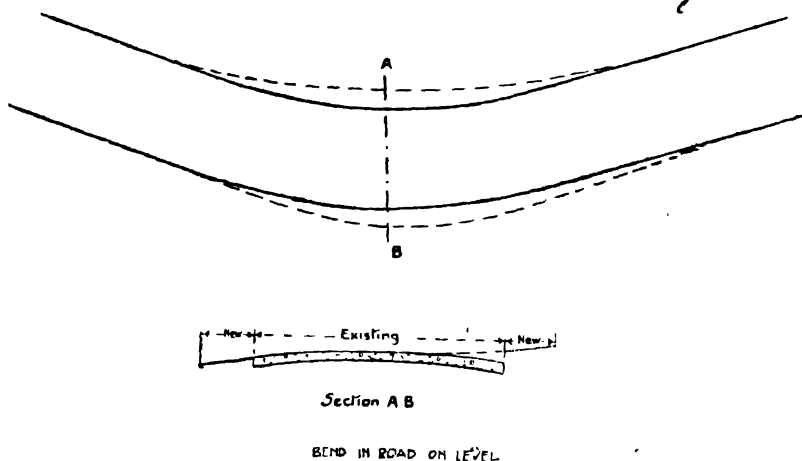
Fig. 33.—Widening and Superelevating Existing Road at Minimum Cost.

by hand finishing : there is, of course, no crown whatever on the superelevated section, and the surface is easily worked with the necessary inward crossfall. Incidentally, if there is any point in the suggestion that the greater area of road surface draining to one side causes a scouring or wearing effect, it is less likely to appear with this class of road than with the macadam pavements.

Superelevating and Widening Existing Roads at Minimum Cost.

There are many cases of road curves in this country where considerable improvements could be made at comparatively little expense. As previously shown one of the greatest dangers

at cambered bends is that of the traffic in both directions seeking the inside of the curve, so that if the outer section of the road can be improved by raising, even slightly, this danger may be eliminated to a large extent. Also it is possible, where widening is carried out, to raise the surface rather quickly on the outside and to lower it on the inside widening. By this means the existing formation need not be seriously interfered with, while superelevation will be obtained in a simple manner.

These proposals are shown in Fig. 33.

This arrangement meets the suggestion that the rate of super-elevation might be varied in the cross-section, so that vehicles could choose their own banking according to their speed. For instance, where a vehicle is travelling at a high speed the tendency is for the driver to continue along the tangent, and this would be checked as he traversed the outer curve, whilst the inner curve would offer similar accommodation for traffic in the opposite direction.

Difficulty of Superelevation in Towns.

In town areas the necessity for superelevation is neither so urgent nor so practicable as on the open road, because lower average speeds are usual and, moreover, footpaths and steps of buildings complicate the question of raising the road surface. To have a footpath below the road is undesirable and simply means removing one trouble by creating another. There are cases, however, in many towns where the footpaths could be raised or lowered without interfering with existing property or causing inconvenience to the public. It will be observed invariably that the road surface at these bends quickly gets into a bad condition, and upon this ground alone the engineer should have no hesitation in recommending the improvement by super-elevation where practicable.

There is one point other than maintenance upon which a definite saving is effected by banking, and that is in the number of gullies and length of surface drains required. These are all placed on the inner edge, and providing there is reasonable head-fall the frequency of the gullies need not be increased. In one case which came to the Author's notice a semicircular road

of 460 ft. radius was being laid on a housing estate and the
engineer could not be persuaded to superelevate the carriageway ;
yet had he done so he would have saved over £200 on surface
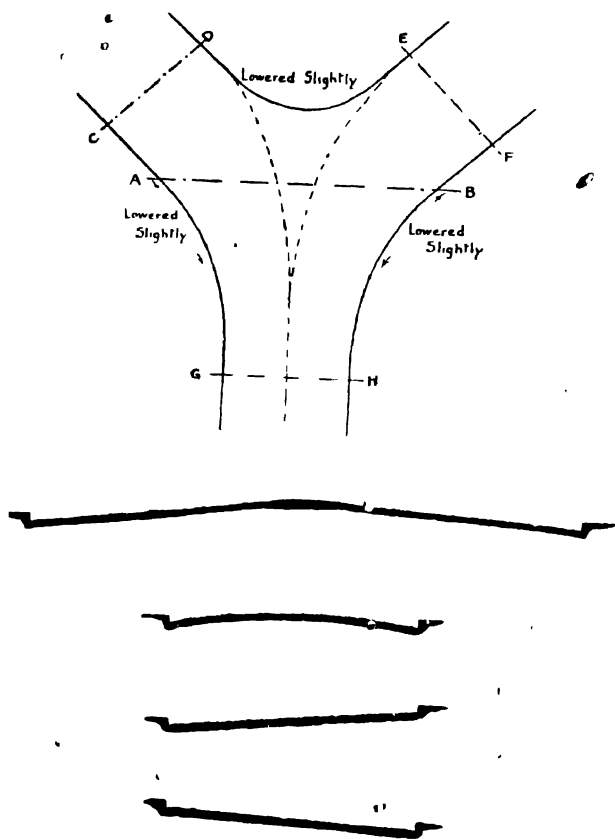
Fig. 34.—Junction of Roads—Superelevation of " Forked Road " ;
Sections are on AB, GH, CD, and EF respectively.

drainage and obtained a road surface with better wearing
qualities and also more suitable for traffic. By arranging a deep
kerb on the inside and a shallow one on the outside of the curve
the difference in level of the footpath may be rendered almost
imperceptible.

Superelevation at Road Junctions.

It is distinctly useful to introduce some superelevation at junctions of important roads where these intersect at less than a right angle. Two examples of this are shown in Figs. 34 and 35 ; in the first case the crown is carried from the centre of the road
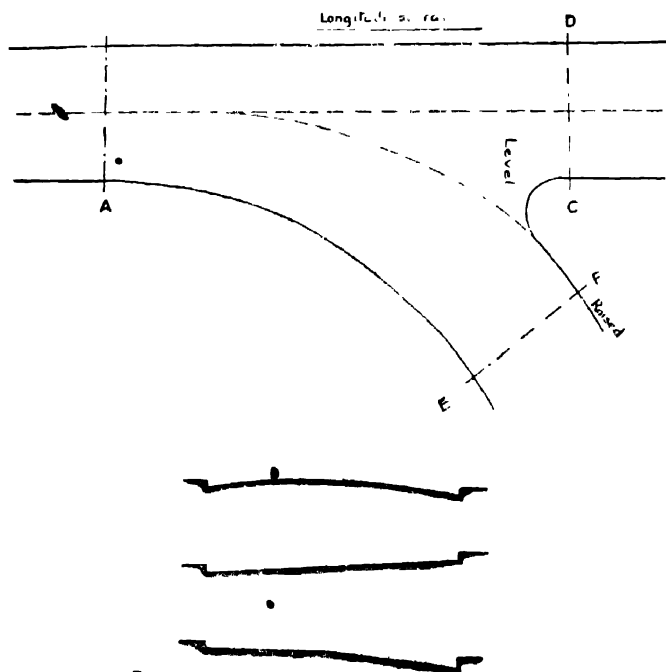
FIG. 35.—Junction of Roads— Superelevation of Branch off Main Road : Sections are on AB, EF, and CD respectively.

just before it "forks" to the outer edge of each of the two branches ; in the second case, the branch road joining the main road is superelevated and the raised outer edge is made to finish at the intersection of the crown in the main road. In order to do this, it is necessary to change the crowned section of the main road somewhat at point CD.

CHAPTER VI

THERE is a vast field of useful work to be done in effecting improvements on roads in hilly country. In the majority of cases a diversion of such roads is not possible, and the engineer will be restricted to improvements of drainage, surface gradients, and bends.

Drainage.

This question has already been alluded to in a previous chapter, but there remain a few special points to be dealt with in this connection. The surface drainage of steep hills is always a matter of anxiety and difficulty to the engineer, as great havoc to the road surface is often caused by the rushing of water in storm periods. Usually one is reluctant to put a good camber on a road with a considerable longitudinal fall, with the result that the surface water collects and travels a considerable distance before reaching the channel. Gradually the streams develop and follow definite lines at high velocity, and the fine material of the macadam, and later the coarser metalling, is washed out, thus forming a channel. Such cases are a constant source of trouble and the cause of high maintenance charges. It is true, of course, that a vehicle will negotiate one of these channels much more easily than a transverse channel. Ample provision, however, should be made for the channel drainage to pass at frequent intervals into the ditch drain, which should be sufficiently deep at its shallowest point to prevent its running back on the road.

A side drain, in pipes with inlets at suitable intervals, on a steep hill may be laid with a steep gradient to provide a high-discharging capacity. This is a sheer necessity, because these drains must cope with the discharge in heavy storms and the

attendant rapid concentration of surface drainage ; the latter
is dependent upon the nature of the subsoil, and no special
formula for run-off need be given here. The rapid flow of a large
volume of water carries with it fine and coarse debris of all kinds,
and causes a choking of the ordinary drainage channels in the
flat regions and a diversion or partial flooding to take place.
This may affect the road by flooding it in the dip or valley, or
depositing debris thereon. As a means of passing the water from
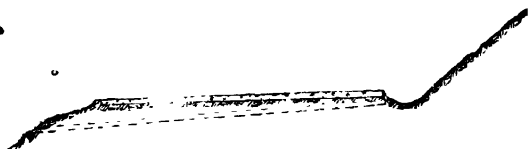
Fig. 36.—Road-dip in Concrete to take Flood Waters.

one side of the road to the other in an inexpensive way the road
surface may be dished or dipped longitudinally with a stone
sett paving or concrete surface of length up to 50 ft., as shown in
Fig. 36. This paving would have a slight crossfall in the direction
of natural drainage of the ground, and a pipe to carry off ordinary
rainfall would be laid under the road at this point. The alter-
native to something of this nature is an expensive culvert or
bridge, and many cases have occurred where, through a blockage

Level

Fig. 37.—Ford in Concrete for Road Crossing Stream.

of the culvert during very heavy floods, both culverts and road
have been washed away and the road destroyed for the passage
of traffic. Fig. 37 shows a concrete ford suitable for a highway
crossing a stream.

Where the road is running on the side of a hill a drain on the
higher side will probably suffice to intercept the flow of subsoil
water and part of the surface water. These should be carried
under the road at frequent intervals or else passed over the
surface with a dip, as mentioned. Ordinarily the subsoil water

‚underneath roads of this type will pass away quickly and the need for tile drainage to the lower side of the road is reduced accordingly.

Capillary Attraction.

This feature of subgrades or subsoils in road engineering has recently been shown to be a factor of great importance in the success of road work. It is accepted that dry subgrades make a better foundation than wet subgrades and that they have a greater bearing power. All other things being equal, therefore, a road which is built on a transverse sloping ground—and in many cases where it falls with the slope of the ground—will have a much drier subsoil than a similar road running over a flat area. Much depends upon the nature of the subsoil and the particular drainage provided underneath the road ; but the movement of moisture down a transverse slope by capillarity is very rapid indeed. Where the subsoil consists of gravel or sand overlying a stratum of clay or other impervious material the conditions are exceptionally favourable to the capillary syphoning of subsoil water.

Design of Gradients.

The arrangement of gradients on the main highways of this country is already settled, and in the majority of cases cannot be improved upon without a very expensive diversion of route. There were certain rules for the selection of gradients in the days of horse traffic which may be readily applied for the motor traffic of to-day. The wear is different, because speeds and loads are different, but the difficulties of tractive effort and braking are similar.

Ruling Gradient.

The ruling gradient is the term applied to the maximum gradient on a particular system of highway. Generally it varies in different localities and in different countries, and the chances of adhering to a reasonable gradient in a large area are not very great. It is well known and appreciated that Telford adopted a ruling gradient of 1 in 30 which became the maximum gradient

on the Holyhead road and the Carlisle–Glasgow road. In India, where inclines of 20 to 30 miles length occur, a ruling gradient of 1 in 18 or 20 is regarded as the most suitable for all-round requirements. American practice shows a ruling gradient of 2 per cent or 1 in 50 for flat districts and 5 per cent or 1 in 20 for hilly districts. Having regard to the usual reserve of power of present-day motor vehicles a maximum gradient of 1 in 20 is not too severe when considered from all points of view. Occasionally it is necessary to break the rule and apply a short steep gradient ; where this is done it should be placed, if at all possible, at the commencement rather than half-way up or near to the top of the hill. This is of advantage both to the horse and the motor vehicle. Ascent is much easier for the animal when it is fresh and for the motor vehicle when it has greatest speed and momentum. Flat sections on a hilly route are desirable, as they enable the vehicle to regain momentum and probably minimize the period of time taken in mounting the hill. The average speed of motor lorries up a gradient of 1 in 20 is about 15 to 16 m.p.h.

Maximum and Minimum Gradients.

The maximum gradient permissible on a road in very hilly and difficult country should be about 1 in 14. This is a dangerous slope, and if possible the curves on it should be flat and the line of vision great. The minimum gradient in an undulating country should be selected to give easy longitudinal surface drainage.

Change of Gradient.

A change or break in the gradient of a road has considerable bearing on the wearing qualities of the road surface. It frequently happens that such points are notoriously expensive in maintenance. The remedy is to improve the junction of the longitudinal gradients in the same manner as on curves by transition. No one will dispute the ill-effects of a gradient over a railway or canal bridge, commencing sharply from a comparatively flat road. The natural result of a vehicle at average speed striking with its front wheels this change of gradient is to set up harmonic vibration and impulsive driving, which motion creates enormously

destructive forces on the road from the driving wheels. The traffic on the down grade is the more destructive as it develops a greater speed, and therefore a greater vibration, although the driving wheels may be running free or even braking. A similar vibration is set up in passing over a bridge where the slope changes from up-slope to level and then to down-grade in quick succession. The inevitable result of this rapid changing of road resistance is the development of corrugation and potholes—potholes, because in many cases poor drainage is the rule rather than the exception.

The remedy for this is the introduction of profiles or changes in the longitudinal gradient which correspond to the transition curves previously alluded to. Far too little attention has been given to this question in the past : the parabolic curve or lemniscate in elevation seems to be well adapted for this change ;
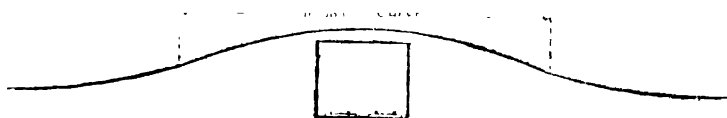
Fig. 38.—Parabolic Vertical Curve for Change of Gradient.

in many instances this can be accomplished by the eye with reasonable success.

Fig. 38 shows the suggested arrangement.

The distance which should be allowed for in making the change is a matter to be decided locally—each case on its merits. It can easily be conceived that the introduction of such curves would increase the amount of filling under the road and that there may be difficulties in the way on account of existing buildings or entrances. The greater the distance between the tangent points the greater will be the filling required, and incidentally the better it will be for the wear of the road itself. Usually the summit of a rise, over railways, etc., is a fixed point and alterations are difficult if not impossible.

The actual amount and length of the transition depends on the relative changes of gradient and upon the actual rate of the steeper gradient.

As an example of the application of the lemniscate for this change of gradient let us suppose a level road required to pass over a railway, with approach gradients of 1 in 20. Select a suitable length for transition, say, 100 ft. : then $\rho = 100$ and a is then determined.

$$\text{In Fig. 39 } \tan 3a = \frac{1}{20} = 0.05.$$

$$\text{Then } 3a = 3° \text{ approx.}$$

$$\therefore \quad a = 1° \text{ approx.}$$

Now $\rho = C \sqrt{\sin 2a}$

and $C = \dfrac{\rho}{\sqrt{\sin 2a}} = \dfrac{100}{0.1872} = 534.$

If $a = 1°$, then from $\tan a$ the height of tangent point where $\rho = 100$ above the level road is approximately 1 ft. 9 in. Constant C being known, other values and heights for ρ between zero and 100 ft. may readily be calculated. This procedure may be followed for all cases of rapid change of gradient.
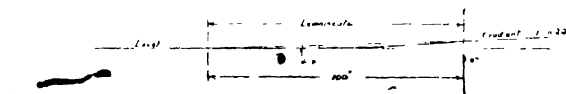
FIG. 39.—Lemniscate for Bridge Approach.

Speed on Hills.

The average speed attained by the normal traffic on a hill road is a vague quantity and depends upon several conditions, viz. the state and nature of the surface or paving, the gradient, the length of the gradient, the length of vision, the number and curvature of bends, and the superelevation on bends. It is particularly useful to have a record of speeds—both uphill and downhill—on roads of any importance, because this will give an excellent indication of rate of destruction which may be anticipated by the engineer in charge of the road. Higher speeds than on the level are expected, and a greater wearing or tearing effect on the road surface due to braking and increased driving effort are unavoidable.

The following table of observed speeds on the Rawalpindi-Murree Road, India, furnished by Mr. A. R. B. Armstrong,

A.M.Inst.C.E., India (P.W.D.), is of particular interest as showing speeds under various conditions :—

						Speed in miles per hour.							
						Lorry.				Touring car.			
						Average.		Maximum.		Average.		Maximum.	
No.	Radius in feet.	Grade 1 in . . .	Banking 1 in . . .	Clear view in ft	Altitude in ft.	Up.	Down.	Up.	Down	Up.	Down.	Up.	Down.
1	25	1 in 14·5	1 in 14	200	6250	8	8½			9	9½	9½	
2	35	1 in 30	1 in 15	300	4200	9½	13			12	10	13	10
3	45	1 in 24	1 in 12	1000	3000	8¼	13½	9	13½	11½	14¼	13¾	15
4	75	1 in 23	1 in 10	115	6000	9¼	14½	9¼	14½	17	16	20½	18½
5{	reverse 80	1 in 11	1 in 15	300	6800					10¼	14	10½	14¼
6	90	1 in 19	1 in 18	1000	6200	14	17			15	13	20½	17
7	275	1 in 21	1 in 50	400	6050	14	17	15	17	16	17	17	19½
8	420	1 in 18		400	5950	12		12½		18	17½	19½	19½
9{	nearly straight	1 in 17		300	4800		22½		23	16	17½	20	19
10	do.	1 in 16		2000	4700		23		23	18	21½	20	24
11	straight	1 in 22		600	2100	10	21	10	29	22	23	26	27½

Limit of Vision.

The limit of vision is really more important in its bearing upon safety on hills than upon the more level portions of highway.' This is because of the higher speeds developed on the downgrade and the possibility of vehicles getting out of hand. Where it is not possible to effect an inside widening—and in many instances this is impracticable—hedges should be cut low and other obstructions removed.

Hairpin Bends.

The occurrence of the hairpin bends on hills, previously alluded to, is so obviously a disadvantage that no engineer would design one if he could possibly avoid it. Moreover, the superelevation of the road surface at such a bend is a matter of some difficulty. The only course open in improving the usual hairpin corner is to work on the outside of the bend by widening, filling, or exca-

vating and superelevating within the limits of safety. In cases like this the pitch of the banking may be increased at the outer edge. The radius of the inner curve should be as great as possible, with a minimum of 40 ft., as this allows the gradient at the inner edge to be more easily negotiated. This rule applies to some extent with slower bends on steep gradients. The up-traffic will naturally seek the outside of these bends, as this part of the roadway offers the advantages of a reduced gradient which to any ascending vehicle is an undoubted attraction. Zigzag corners or reverse curves occur frequently on the highways of this country—more particularly on hills—and similar treatment should be given. A careful selection of the site should be made so that the connection of two points is effected, if possible, by one bend only. The rule for limit of vision should be followed carefully on freak bends of this type.

The Nature of Paving for Hill Roads.

The selection of a suitable surface for hilly roads is one of the most difficult problems presented to the road engineer. Various conditions must be met to give a satisfactory road surface. It must be non-slippery, yet present an even surface ; it should offer a low tractive resistance to traffic ; it should be strong enough to resist movement and wear due to driving or braking ; it should offer a good grip for horses, particularly on the up-side. These requirements cannot easily be complied with, and many different arrangements of road paving have been adopted in various parts of the country. The main difficulty to-day is the necessity of catering for the horse traffic on the up-grade ; were it possible to eliminate the horse entirely from the road—and this is by no means unlikely in the near future—the engineer would be able to provide a smoother surface, which need not afford the grip for horses as is at present necessary.

There is considerable prejudice against smooth-surface pavements as they are generally believed to be slippery. From the motor driver's standpoint a smooth surface on any road of reasonable gradient is less slippery and less dangerous than uneven sett-paved or waterbound macadam surface.

The practice hitherto has been : (1) to pave the whole width

with large non-slip grit setts, (2) to lay the whole width with waterbound macadam, or (3) to pave the up-side with setts and the down-side with macadam.

1. Grit setts.

The non-slippery nature of this class of sett paving has made its adoption for hilly work a matter of course. Unfortunately, the results generally show a very uneven surface which has a disastrous effect on traffic. It is obviously more serious, from every point of view, to have an uneven surface on a hill than upon a level stretch of road ; vehicles travelling up or down have powerful driving or braking effort transmitted through their rear wheels, which, if they jump across a pothole, cause immeasurable damage both to the road and the vehicle.

One method of obtaining even surface conditions is to lay a concrete foundation beneath the setts, which should be preferably small and laid upon a good sand cushion. A better plan is to use either small 4-in. non-slip granite cubes or setts 6 in. deep. Where the up-side only is to be paved with special grit or other non-slip setts, the blocks may be toothed into the down-grade paving.

2. Waterbound Macadam.

This forms one of the most generally adopted road surfaces for hilly work. It forms a good foothold for horses and for the driving wheels of motor vehicles ; the tractive force, however, is excessive. One of the chief objections to the macadam surface is the easy disintegration by the scouring action of surface water, thereby causing loose stones to lie on the surface. Some camber is necessary to prevent the channelling due to the longitudinal rush of water. To a large extent macadam roads, where not too steep, may be tarred or tar-sprayed, at least on the down-side, and this should have the effect of binding, temporarily, the macadam and preventing the disintegration caused by high-speed or braking.

3. Setts and Macadam.

One of the principal advantages of this arrangement is that it offers two different surfaces, either of which, providing the road

is sufficiently wide and straight, may be utilized by the traffic up or down.

Some excuse may be permitted for transgressing the rule of the road on hills, providing there is no danger to other traffic. The longitudinal joint between the two pavements is usually a source of trouble and an important item in maintenance. It is at this point that water enters into the road most readily, especially with waterbound macadam, thus causing a series of potholes and waves. A tarred macadam surface gives a better result, since the joint against the sett paving can be waterproofed throughout.

Wheelers.

The provision of wheelers to reduce the tractive effort for road vehicles is well established in the early history of road-making, and there is a tendency to revive the principle to-day for modern motor traffic. The suggestion is by no means a frivolous one. One has only to observe the passage of traffic along a busy road which will only accommodate two lanes of traffic to realize the tremendous wear upon the four longitudinal strips of roadway. It has been suggested by Lord Montagu of Beaulieu that " plateways " should be laid down for heavy and concentrated traffic. Much depends upon the kind of paving and the foundation as to the effect of this concentration.

In the case of hilly surfaces it is an advantage to have the traffic kept distinctly to either side, according to the rules of the road. The use of wheelers on the up-side will make this possible. Hitherto the practice has been to lay blocks of granite or stone about 3 or 4 ft. long and 12 or 16 in. wide at 4 to 5 ft. centres.

The advent of concrete paving suggests that concrete wheelers would have a decided advantage over the blocks, as the transverse joints of the latter would be absent in the former. The paving of non-slip setts between the wheelers on a concrete foundation should be carried out at the same time, and the whole subjected to the precautions necessary for concrete paving to secure a hard-wearing surface. The arrangement of concrete wheelers is shown in Fig. 5.

Where sett paving is laid on a stone or other ballast foundation,

movement of the setts is liable to take place both by tilting and by the setts being carried bodily downwards by the high speed and rush of down traffic. The principle of paving the setts in segment shape is worthy of notice, as on hills they may be arranged in arch formation to resist the down-thrust of the traffic.
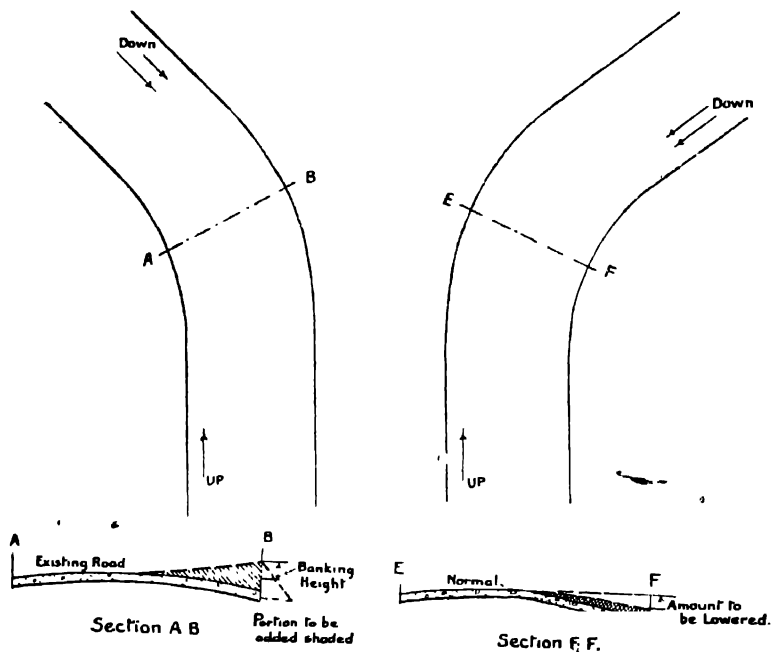
FIG. 40.—Superelevation of Dangerous Bends on Hill Roads.

Superelevating Dangerous Bends on Hill Roads.

As shown in Fig. 33, it is possible to improve the banking of a road at the bend by widening without seriously altering the former cross-section of the road. In the case of hill roads more drastic treatment may be resorted to, either on the inside or the outside of the bend, according to the direction and gradient, as indicated in Fig. 40.

CHAPTER VII

THE road widths of this country, in the majority of cases, were established in the early days of macadam construction, and, as yet, no great attempt has been made to adapt them on a large scale to meet the development of modern traffic.

The wider roads have come to be regarded as main roads chiefly on account of their width, the narrower routes being comparatively little used by the more rapid traffic. There are many instances of main roads of very narrow widths to-day, generally in some village or town, where existing buildings have militated against widening schemes and improvements. Where this is the case the cost of widening is naturally very considerable, and local funds are usually insufficient to effect any improvement. The national taxation of motor vehicles for road improvement purposes has now enabled schemes for widening, removal of dangerous corners, and the construction of by-pass roads to be carried out without their becoming a heavy drain on the finances of the local authorities. Unfortunately, the substitution of by-pass roads to divert through traffic from towns or villages usually meets with local opposition on the ground of loss of trade to the tradespeople : this fear is more imaginary than real, and from the road user's point of view only serves to emphasize the need for diversion.

These improvements will no doubt take many years to accomplish, but in the meantime, in the absence of those difficulties which present themselves in urban districts, road-widening schemes in rural areas on a large scale are possible.

There is a considerable difference of opinion amongst engineers as to the road widths which should be adopted for main and other roads in urban and rural areas, and it is advisable before

coming to any conclusion on the point to consider carefully the question of traffic statistics and the increase in the volume of traffic from time to time.

A general traffic census is now taken annually in this country, and much useful information has already been obtained and collated. The purposes of a census may be detailed as follows :—

1. To determine the average daily volume of traffic using the highway and the nature and destructive effect of the traffic.

2. To establish a record of the development and increase of motor traffic and the decrease of horse traffic.

3. To determine the variation in volume and congestion at different periods of the day, week, month, and year.

4. To enable an estimate to be formed showing the probable speeds of the vehicles and the average distances between them.

5. To determine the difference in volume of traffic before and . after any improvement or reconstruction.

6. To enable the cost of road maintenance per unit vehicle to be determined.

7. To assist the engineer in designing, maintaining, or reconstructing the highway.

8. To assist the police authorities in allocating staff for regulation of traffic at congested or dangerous points.

9. To assist in drafting regional town-planning schemes.

The Road Board Form No. 5 has been arranged to enable this to be accomplished, and it will be seen on the form given below that motor vehicles are separated under different headings according to the tyres, types, and weight. It is important to note that wherever a traffic census is taken it should be on the lines suggested by the Road Board in order that comparisons may be made upon the same highway running perhaps through several counties or boroughs. The census will usually be taken by the local authorities.

' Whilst adhering to the conditions of this form there is no reason why additional information should not be recorded at the same time. This might include the recording of whether vehicles are light or loaded, since the unloaded vehicle may do much more damage to the road under some conditions than the same

Form No. 5. COUNTY ....

THE ROAD BOARD—STATISTICS OF TRAFFIC.

Where taken .... Date. ,..........19

(For note and instructions see back.)

Condition of Road .... Condition of Weather ....

Time : From ....m. to ....m. Enumerator's Name ....

Classification of Vehicles.	Enumeration of vehicles.	Total.
	Each vehicle to be indicated by a stroke from right to left. thus /, except in the case of the item marked thus ‡. see notes below. ⓑ	
Ordinary Cycles		
Motor vehicles. Motor Cycles		
Motor-cars, (including Motor Cabs and any other motor vehicles not specified)		
Motor Vans (covered)		
Motor Omnibuses		
Motor Lorries (rubber tyres)		
Trailers to rubber-tyred lorries		
Motor Lorries (steel tyres)		
Trailers to steel-tyred lorries		
Light Tractors		
Trailers to light tractors		
Traction Engines		
Trailers to traction engines		
Horse-drawn vehicles. Light Vehicles (one horse)		
Light Vehicles (two or more horses)		
Heavy Vehicles (one horse)		
Heavy Vehicles (two or more horses)		
Omnibuses (two or more horses)		
Tramcars ( )†		
Horses (led or ridden)		
Herds of Cattle‡		
Flocks of Sheep and Pigs‡		
Hand Carts and Barrows		
Horses Drawing Vehicles¶ (not to be filled in by the enumerator)		

NOTES, ETC.

Steam rollers are not to be recorded
† Insert " Electric." " Steam " or " Horse," as the case may be.
‡ Approximate number in herd or flock to be given and encircled thus (21) (9) (11)
¶ The total number of horses drawing the vehicles entered above should be calculated and their number given separately on this line
NOTE—The exact spot where the statistics of traffic are taken must be indicated on a small sketch plan on back of Summary sheet. The plan should show the width of
   (a) the metalled carriageway,
   (b) the footpaths,
   (c) the roadside margins.

vehicle when loaded. If possible the commercial motor traffic should be separated into approximate tonnage, for instance, 1 ton to 2½ tons, 3 to 4½ tons, and 5 to 6 tons. These weights should present no difficulty to the enumerator, and with a little practice this classification becomes a very simple process. The kind of tyres, whether solid or pneumatic, should also be recorded.

STATISTICS OF TRAFFIC.

Where taken.......................... Date......................
Conditions of Road.............. Conditions of Weather...............
Time : From .... Enumerator's Name.......... ......

Classification of Vehicles	Enumeration of Vehicles.		
	Loaded.	Unloaded	
Ordinary Cycles			
Motor Cycles			
Motor-cars			
Motor Vans or Light Lorries up to 1 ton, solid tyres			
Motor Vans, do. (pneumatic tyres)			
Motor Omnibuses (solid rubber tyres)			
Motor Lorries, 1–2½ tons (solid rubber tyres)			
Motor Lorries (3–4½ tons, do)			
Trailers (rubber tyres)			
Trailers (steel)			
Motor Lorries, 5 tons (rubber tyres)			
Trailers to, do do.			
Do. do. (steel)			
Light Tractors			
Trailers to, do.			
Traction Engines			
Trailers to, do.			
Light Vehicles (one horse)			
Light Vehicles (two or more horses)			
Heavy Vehicles (one horse)			
Heavy Vehicles (two or more horses)			
Tramcars			
Horses (led or ridden)			
Herds of Cattle			
Flocks of Sheep or Pigs			
Handcarts or Barrows			
Horses drawing vehicles			

............STATE HIGHWAY DEPARTMENT

TRAFFIC CENSUS

Station at.................   ....Date

North South ⎱   ....Weather
East   West ⎰ Bound Traffic   ....Observer

Hours	Horse Drawn Vehicles			Motor Vehicles								
	Passenger	Freight		Motor Cycles	Passenger				Trucks			
		One Horse	Two Horses		2 Passenger	5-7 Passenger	Busses		2 Ton and Less	Over 2 to 5 Tons	5 Tons and Over	Trailers State Capacity Tons
a m 6-7												
7-8												
8-9												
9-10												
10-11												
11-12												
p m 12-1												
1-2												
2-3												
3-4												
4-5												
5-6												
6-7												
Totals												

Farm to Town   Inter-town   Through or Tourist   Remarks

Suggested Tally Sheet for taking Traffic Census.

In the case of the motor omnibus it is especially useful to note the state of loading, average speeds, and habits of these vehicles for the purpose of assessing the damage caused to the road.

On page 72 the schedule drawn up by the Author will enable these points to be recorded and the Road Board Form complied with at the same time.

The schedule on page 73 shows the type of form used in some of the American States for detailed traffic census.

To establish a record of the development of motor traffic and the decline of horse traffic the census should be taken at a definite period or periods of each year, and a graph plotted showing in what direction the development is taking place. It is important that no comparisons should be made unless the road surface and freedom from obstructions are identical.

Hourly Variation of Traffic.

To determine the frequency of traffic at different periods of the day or week will enable the engineer to record the most congested part of the time that the road is under observation. In taking an hourly census the enumerator will have no difficulty in keeping the hourly records separate. The figures can readily be tabulated and totalled for daily comparisons. A typical hourly census on a busy main road running between Lancashire and Yorkshire is shown in Fig. 41.

The record on some days of the week will show a heavier volume of traffic than others. In some cases the week-end traffic, though of a different nature, will be much greater than normal week-day traffic. These points should be carefully noted in view of the fact that week-end traffic consists principally of pleasure cars and the majority of such traffic is pneumatic-tyred. The records will also show that at certain parts of the month the traffic will be heavier than at others. Hourly variations shown by the records will enable the engineer to estimate approximately the average distance between those vehicles running in the same direction. This information may be supplemented by records of the actual speed of vehicles where circumstances warrant it.

In the past this information has been left to the police authorities, but the time is opportune for the road engineer to consider

this question in its relation to the destruction of the road. crust.

In all cases of weekly, monthly, or periodical census of traffic the weather conditions should be noted so that no unequal comparisons are made.

Seasonal Variation of Traffic.

Seasonal variation of traffic is perhaps of the greatest importance to the road authorities, as there is a vast difference between
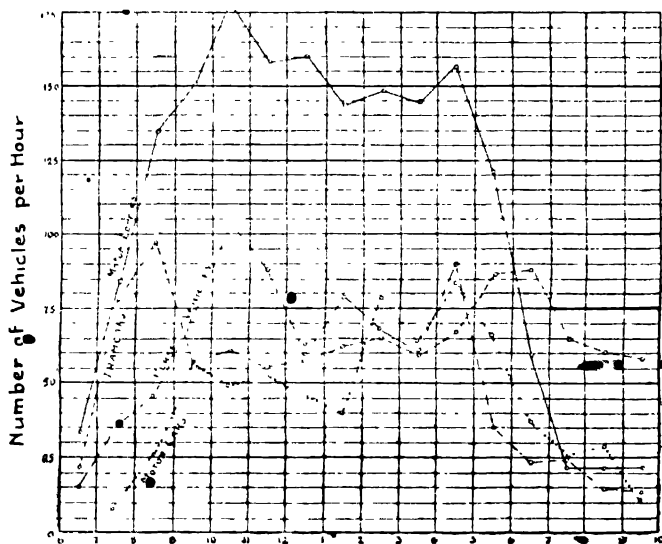
Fig. 41.—Diagram showing Hourly Variation of Traffic.

traffic in midsummer and traffic in midwinter. Where records are kept monthly a fairly accurate register of the seasonal variations may be secured. Failing monthly records a quarterly census, taken, say, in the months of January, April, July, and October, will give a fair estimate of the change taking place. It will be realized from this comparison that the road surface is very much more subject to wear during the summer than in the winter, so far as the traffic is concerned.

If the average daily traffic is 2000 vehicles for a 16-hour day, i.e. 6 a.m. to 10 p.m., the average hourly traffic is $\frac{2000}{16} = 125$, which, at a speed of 15 m.p.h., will give on the average a clearance of 633 ft. between each vehicle.

The Question of Speed Affects Spacing.

It does more than this, however, because at high speeds more clearance is necessary for safety ; indeed, it can be argued that the number of vehicles passing a given point at a speed
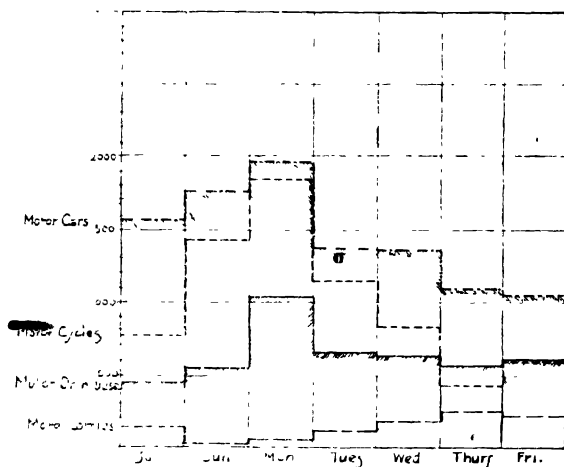
Fig. 42.—Graph showing Daily Variation of Traffic on the Blackpool Road, 1921.

of 25 m.p.h. would be no greater than the number of vehicles passing with safety the same point at 15 m.p.h. Whilst a road that will accommodate only two streams of traffic will admit of an enormous number of vehicles per hour, in view of the great variety of motor traffic so restricted a width is undesirable.

To illustrate this point the statistics of the summer traffic records on the Blackpool–Preston highway, by the courtesy of the Lancashire County Surveyor, Mr. W. H. Schofield, A.M.Inst.C.E., are shown in the graph, Fig. 42.

On this road, for the most part, there is only one stream of traffic in each direction, and once a vehicle has taken its place in the stream it is almost impossible for it to pass the preceding vehicle ; it is only necessary to experience the discomfort of this situation to realize that wider roads are a necessity to modern traffic.   It will be obvious that the faster the stream the more difficult it will be to pass or overtake another vehicle.

If 1000 vehicles passed a given point in one hour at a speed of 20 m.p.h. the spacing, centre to centre, would be 150 ft., from which it will be seen that a highway carrying one stream in each direction can accommodate a total traffic of 2000 per hour.

Where tram tracks exist the question of road widths is a matter for other considerations, and the foregoing points do not apply in the same sense as upon roads free from tramway systems.

The determination of the volume of traffic before and after an improvement is of particular interest both to the engineer and to the road user.   If an increase takes place then some relief will probably be noticed on adjacent or alternative roads.

The cost of maintenance of a highway per unit vehicle or unit load is a matter of the highest importance in balancing utility against expenditure of public money ; it also enables a comparison to be made of road material on different sections of the road as well as on different roads of the same locality.

A census taken on the lines indicated by the Author will facilitate the tabulation of types of vehicles and their tyre equipment, and assist in placing the responsibility for corrugation or other forms of road destruction.

The advantages of a traffic census in directing the attention of the engineer to those points of the road requiring special consideration hardly needs elaboration here.   He will be able to allocate his expenditure on maintenance and improvements to those sections of the road which most require it.   Comparisons of maintenance and wear with traffic are obviously useful in judging the qualities of the different sections to varying conditions obtaining along a particular road.

The regulation of traffic whilst primarily concerning the police authorities is one which requires some guidance from the road

authorities, and a census of traffic is useful for selecting those points and times where and when police regulation is advisable. On a heavily trafficked road having numerous important cross-roads direction of the traffic would be thoroughly justified at all such points should a traffic census be fairly consistent throughout. It is useful in arranging for diversion of traffic occasioned by important events, such as processions or other similar public functions.

Road Width.

It is difficult to give any definite figures as standards for road widths. It is, however, easy to give minimum widths of carriage-way for certain purposes as a guide for improvements or future design. The average width of an ordinary vehicle may be taken as 5 ft. and the maximum width for this purpose is 7 ft. 6 in. The following table represents most of the widths in this country to-day.

Width of carriageway	Length of road.	Type of road.	Traffic accommodated.
13′	Not exceeding 250 feet	Residential cul-de-sac (Garden Suburb)	Two streams, to pass at slow speed.
16′	Not exceeding 750 feet	Through road in residential area	Two streams, to pass at moderate speed.
20′	Not exceeding 1000 feet	Do. do.	Do., at higher speeds.
24′	Unlimited	Secondary Main Road.	Three streams, one for slow traffic.
30′ to 48′	Unlimited	Main Road.	Four streams, one fast and one slow in each direction.

Note.—Ministry of Transport latest standard is 10 feet of width for each line of traffic.

Where a double tramway track exists the width should be

correspondingly greater, as this takes up a centre width of about 13 or 14 ft. The new town-planning roads of 100 to 120 ft. width ' in many cases provide for a centre high-speed or fenced-in tram-way, which reduces the effective width of the carriageway very considerably and furnishes two independent roads each of about 20 or 24 ft. width and taking traffic in one direction only. This is unfortunate for road users, as they will not have the security or freedom of movement as when travelling on a 40 or 50 ft. road.

Where new roads are being made it may not be advantageous to construct the full intended width of the carriageway, and in such case provision may be made by laying wider footpaths and verges so that these may be reduced when the necessary development of land and traffic has taken place.

In France the national roads are 66 ft. wide with the surface improved not less than 22 ft. Departmental and provincial roads have improved surface of 20 ft. width, whilst the " neighbourhood " roads have carriageways 16 ft. wide.

In town work the widths of carriageway may take dimensions very different from those on the open road : traffic is often slower, intersections frequent, and the conditions generally difficult. Consequently the main roads should be as wide as possible to provide for slow vehicles, fast traffic, and also public vehicles such as the omnibus and tramcar.

Arterial Roads.

In the proposed new traffic arteries for Cleveland, Ohio, the roadway for four classes of highway are 80, 60, 55, and 42 ft. respectively. The 55-ft. road will provide for four fast and two slow lines of traffic, or about 9 ft. for each.

As an average value for existing British main roads the full width may be taken at 50 to 60 ft. and the carriageway at 24 to 30 ft. New arterial roads in connection with town-planning schemes in this country are 100 and 120 ft. wide; other roads are 75, 60, 50, and 42 ft. wide, according to their relative importance. In one instance, a road of 150–200 ft. has been proposed to link up Manchester with Liverpool. There seems little doubt that the principal new arterial roads will have a complete width of 150 ft. or thereabouts in the near future. The intention is to

construct a 30-ft. carriageway on either side of the centre, which would be reserved for fast enclosed electric tram traffic ; one section only, however, would be constructed in the first instance.

Where arterial roads of this character have been constructed, it has been clearly shown that a single road of 40 or 50 ft. is superior in every way to two narrow roads 30 ft. wide.

The construction of arterial or new main roads in various parts of the country within recent years is due to the enterprise and initiative of the local or county highway authority and the Ministry of Transport. Several large schemes have been completed and many others are in hand. These roads pass for the most part through virgin country although close to large towns and busy areas, and in many cases they open up districts which have hitherto only been accessible by narrow circuitous routes : incidentally the value of the land along the route is immediately enhanced and building development expedited. One effect of the new arterial road is to attract traffic from the former routes because of greater comfort and safety and a lesser distance to reach a given point. It is to be hoped that when Joint Town-Planning is in operation in the various populous areas that arterial road construction will be one of the first planks in the programme of each Joint Committee.

Regional Census of Traffic and Relation to Town-Planning.

The traffic records taken by the Ministry of Transport deal principally with main-road traffic taken at definite points over the whole country. A regional census concerns more particularly local conditions over a zone area surrounding one or more large towns. The object of this census is to record the number and nature of the traffic, whether pleasure or commercial, heavy or light, etc., as it passes along the main arteries, to and from the industrial centre, and to trace the route followed by those vehicles through the area.

In order to do this it is necessary to record the registration number of each motor vehicle, and the time of passing a particular station point.

A census of traffic in this manner was taken in June, 1922, in

South-East Lancashire, over an area of a 15-mile radius from Manchester.

About 500 enumerators were engaged, the registration numbers of the traffic being noted, and also the approximate time of passing by, recording the numbers in separate columns for each 10-minutes interval from 8 a.m. to 8 p.m. Thus each vehicle was traced for a whole day over the whole area, and most valuable information secured for regional town-planning purposes.
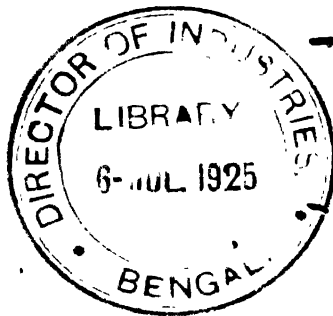
THE demands of heavy mechanical traffic and also of horse-drawn vehicles in recent years have brought about the general adoption of sett or block paving.

The types of block paving in existence in this country may be classified as follows :—

        (*a*) Grit-sett paving.
        (*b*) Granite-sett paving.
        (*c*) Wood-block paving.

Grit-Sett Paving

As a general rule, grit setts are laid on a non-rigid surface, the reason for this being that the base of the paving must offer a cushioning effect for the setts when subjected to impact of wheel loads. This fact renders it impossible to maintain a smooth surface for any length of time, and in addition there is a likelihood of potholes developing, due to a splitting of the setts themselves. This splitting will occur in vertical planes, since the setts are laid with the natural beds of the stone vertical, or at right angles to the bed of the road, and thus there is an easy passage for surface water to percolate to the foundation. When this occurs subsidence of the split stone may be expected. It is not difficult to keep a grit-sett road in a good state of repair for lighter traffic so long as the defects are dealt with in the early stages.

Method of Raising Setts for Repair of Potholes.

Where one sett has subsided it may be raised by means of a simple device which the Author has designed. This consists of two rods about 12 in. long. with a ring at one end and the other

tapered and formed like a fish-hook, as shown in Fig. 43, so that it may be driven down at the opposite corners of the sett, below the the base, and turned, and then lifted by the leverage of crowbars. The foundation having been restored, a new block may now be rammed and grouted into position. As an alternative to this, concrete may be used to replace the defective sett or setts, thus obtaining a tight joint with the adjoining paving. It would be necessary, however, to keep traffic off the surface for several days in order to give time for the concrete to harden. Grit setts will be found most useful for really hilly work and in localities where
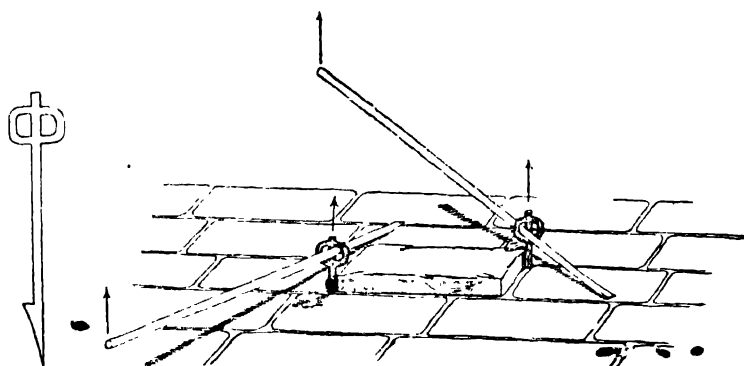
FIG. 43.—Lift Hook for Easy Raising of Single Setts from Paved Roadway.

the stone is at hand. The grouting of this kind of paving requires special care, as it is difficult to keep out water when laid upon a non-rigid foundation. It is usual to fill the joints by brushing in chippings prior to grouting with a suitable mixture of pitch grout.

Granite Setts

This kind of paving is decidedly more suited to modern conditions than grit setts, granite being much better able to resist impact blows from traffic whether on a rigid or non-rigid surface. The setts may be of various shapes, generally either rectangular or cube-shaped. In the past, when non-rigid foundations were the rule rather than the exception, deep setts were

often used in order to strengthen the pavement and at the same time provide against wear for a long term of years. The tendency to-day, however, is to lay new paving upon a concrete foundation, and it is unnecessary to adopt setts deeper than about 5 in. Fig. 44 shows cubes paved on a ½-in. to 1-in. bedding course of sand and on a concrete foundation.
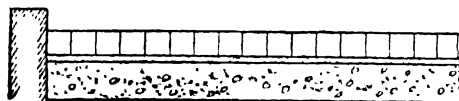
FIG. 44.—Granite Cube Paving on a Concrete Foundation.

Covering Area of Various Sizes of Granite Setts.

The depth of the setts themselves influences the cost of the work, the covering area per ton increasing with the reduction of depth. The following indicates the approximate covering area for different sizes of a first-class Welsh granite sett :—

Dimension of sett.		Covering area.
Depth.	Width.	Per ton.
6 in.	3 or 4 in.	3½ sq. yd.
5 in.	4 in.	4 sq. yd.
4 in.	4 in.	5 sq. yd.

If the base of the sett is not flat on the foundation the action of heavy road traffic will lever up the jointing grout, under which process a soft granite will obviously wear faster than the hard kinds. The blocks, the depth of which should be accurately gauged, should be laid as closely as possible, and not more than ⅜ in. apart, on a ½-in. bedding course, the usual direction of the joints being at right angles to the centre of the road. The best bedding consists of sand or a similar fine material, such as limestone dust. The blocks should now be well rammed into position and jointed. Another form of cushion which has been used with success is asphalte or mastic : this has elastic properties, and the setts are paved directly after the mastic is laid on the concrete

foundation.   The principal objection to its use is the increased cost.

Grouting of Granite Setts.

There are various kinds of grouting, namely :—

(a) Granite chippings (½-in.) brushed into the joints and subsequently flushed with a mixture of pitch and tar-oil, and
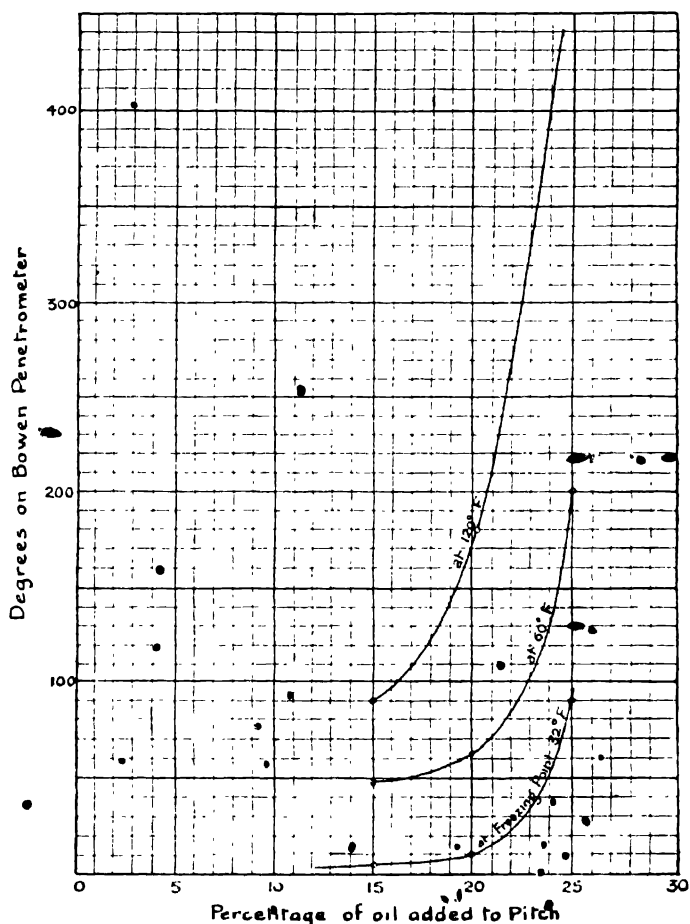
FIG. 45.—Graph showing Relation of Penetration to the Percentage of Oil added to Pitch at Different Temperatures.

then covered off with fine chippings or dust. Fig. 45 is a graph showing the proportions and penetration of different mixtures of pitch and oil at different temperatures. Fig. 46 shows the monthly variations of pitch and oil mixtures over a period of twelve months, taken from actual quantities used on various road-paving works. This shows that the tendency is to add too much oil in the winter, thus making the grout soft in summer, and vice-versa for grouting done during the summer.
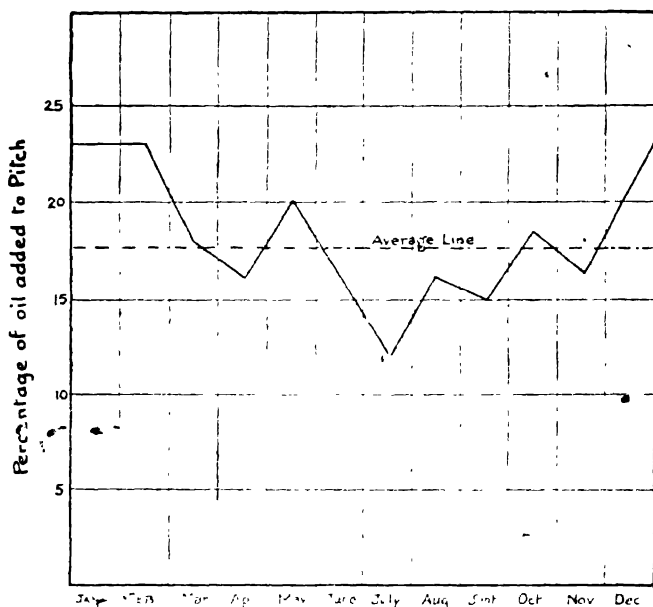
FIG. 46.—Grap' showing Monthly Variation of Pitch and Oil Mixtures from Actual Returns.

(b) Bituminous mastic fillers, consisting of bitumen mixed with heated sand or limestone dust.

(c) Straight bituminous fillers.

(d) Cement grout alone or pitch mixture at the lower portion of the joint and cement at the upper portion and surface.

Recent accelerated wear tests in America have proved that both types of bituminous filler are superior to cement grout in resisting impact from heavy mechanical traffic, the soft filler

acting as a cushion. Of the two, the mastic fillers are to be recommended on the ground of economy.

Nidged or Dressed Setts.

These are specially dressed setts, usually more expensive than the ordinary setts, and of better shape. Consequently they pave closer together and give a much smoother and cleaner surface than the other kinds of sett paving. Among others they have been used with good results in Scotland, where the setts are about 6 in. wide. The paving is of neat appearance, is less noisy from vehicles, and more comfortable for pedestrians to walk over than the ordinary granite sett.

Wood-Block Paving

Wood blocks impregnated with creosote form a durable, smooth, and noiseless road material. This kind of pavement is usually to be found in cities, where noiseless conditions are urgently required. Wood blocks are particularly suitable for bridges, owing to their lightness and resilient qualities. They are sometimes used alongside tram rails in a single row, to reduce the noise from the cars. Hard woods are not to be recommended : a medium or soft-wood paving will give the most satisfactory results. The timber most generally used is obtained from Sweden, Archangel, and Finland. It should be heavy, close-grained, of uniform texture, and susceptible to impregnation by creosote. The quantity absorbed should be between 8 to 10 lb. per cu. ft. of timber.

Other tests which may be applied to wood blocks are :—

(a) The number of annual rings per inch.

(b) The oil content in lb. per cu. ft.

(c) Water absorption after 24 hours' immersion.

(d) Shearing strength.

(e) Impact tests effected by hammer blows on small cylindrical cores until failure.

(f) Expansion or Shrinkage Tests : Special blocks are maintained in water vapour for one year, dried in vacuum at 140° F. to constant weight, and again measured. The change in length and width should not exceed 4 to 5 per cent.

Method of Laying Wood Blocks.

They should be laid on the smooth surface of a concrete foundation, the depth of which should be not less than 6 in. of 6 : 1 composition where not reinforced and on good average subgrade, as shown in Fig. 47. On no account should the blocks be laid on a bedding course, as this assists in causing an uneven surface, especially when the jointing material softens in hot weather. The blocks may be dipped in a hot soft pitch composition prior to paving or laid dry. The joints in each case should be filled up with pitch, close to the surface, and the remainder filled with cement-sand.

Expansion and Contraction of Wood-Block Paving.

In the case of soft paving, which is noiseless and less slippery than hard wood, it is usual to allow for an expansion joint

Fig. 47.—Wood Blocks Paved on Concrete Foundation.

alongside the kerb. The expansion and contraction of this class of blocks is one of the main difficulties met with in the course of maintenance. In hot weather the dimensions of the blocks are usually the minimum and under these conditions the courses are most slack. It is possible to tighten a slack wood-block paving by taking out a few courses at intervals, say of 200 to 300 ft., and pressing therein jack frames, i.e. three special jacks in each cutting, which are expanded and the remainder of the block paving closed. It is possible to move the blocks a distance of 30 in. in a length of 150 ft. It will show a movement against the traffic double that of the blocks with the traffic. One advantage of the use of this apparatus is to obtain initial compression as compensation for ultimate shrinkage. The shrinkage which occurs in hot weather will be least on those roads which are shaded by high buildings and greatest where the road is most exposed.

Preservation of Wood-Block Paving.

The treatment for the preservation of wood-block paving should be effected where necessary by cleaning the joints and flushing with hot coal tar of specific gravity of about 1·20 at the rate of about 1 gal. per sq. yd., which should be swept in with brushes or squeegees.   An application of sand is necessary to prevent the wheels of traffic lifting the tar.

Brick Paving.

This kind of paving is practically unknown in this country, but is fairly popular in America.   It consists essentially of vitrified bricks laid on edge with close joints, grouted with cement or bitumen, and paved with a bedding course, usually upon a

Fig. 48.—Diagonal Paving

concrete foundation.   It has a good appearance, but it is not now used in large cities and heavily trafficked areas.

Diagonal Paving.

The usual method of laying setts at intersecting roads is that of diagonal paving to form a gusset.   This is done in the interests of horse traffic, but it has a further value in that *it presents a lower tractive resistance* and wears better than the straight or transverse joints.   Where consideration for horse traffic is of secondary importance, diagonal paving would probably prove superior to the ordinary straight joints.   In the case of wood-block paving a diagonal arrangement of the blocks forms an admirable carriageway, as shown in Fig. 48.

Segmental Paving.

Segmental paving, such as Durex or Kleinpflaster, which has been used with varying success, provides a diagonal paving, but

. it offers also certain weak points at the intersection of the segments, more especially as 'this class of paving is confined to setts of small dimensions. The setts are paved to form segments or arches in plan, of a span of about 5 ft. Where the segments touch or spring from each other it is not easy to mitre the blocks, and generally it is at these points where potholes or waves begin. It will be obvious that when traffic is passing in a direction against the arch thrust the road will be less likely to deteriorate. In the other direction the blocks have less resistance and the arching effect does not exist ; consequently, this portion of the· road will more readily show signs of wear.

Tramways

The existence of tramways on the main and secondary roads of this country is sufficiently extensive to warrant consideration of their relationship to the general maintenance of the highway. The development of electric rail traction preceded by many years the introduction of motor vehicles, and the establishment of the permanent way of these tramway systems has involved a large outlay of capital, which in many instances would not have occurred had the motor omnibus been developed earlier. It is likely, therefore, that this type of traffic will have to be considered for some time to come, especially in view of the fact that the tramcar has a much higher carrying capacity than the motor omnibus. This fact is of great importance during " peak " load periods, i.e. those periods of concentration of traffic required to transport passengers in large numbers to and from their place of employment. The responsibility for the maintenance of the tramway track rests entirely upon the tramway authorities : the width of track comprises the paving between the rails and that for a width of 18 in. outside the outer rails. The type of paving and the treatment of foundation should be such as to resist the excessive wear that invariably occurs alongside the tram rails, at the same time providing an even surface under all conditions. The standard gauge of the rails, namely, 4 ft. 8½ in., coincides approximately with the width of a large percentage of the vehicles now on the road. These vehicles, seeking the crown of the road, almost invariably travel with their wheels on the

rails or the paving immediately adjoining them. This concentration of traffic leads to excessive wear of this part of the road, and incidentally of the rails themselves, thus causing longitudinal grooves, which may become dangerous to traffic. On the other hand, it is possible for the blocks adjacent to the rails to become tilted owing to movement of the rails themselves. This may be largely prevented by :—

(a) Bedding the rails firmly upon the concrete foundation. This may be effected by running a course of hot tar and chippings under the flange immediately after laying. The heaviest rail load to be allowed for is about 20 tons, the weight of a large type of car fully loaded.

(b) Welding the joints : this reduces movement and vibration.

(c) Anchoring the rails to the concrete.

(d) Effectively parging the web and rendering watertight the longitudinal joints between the paving and rails.

The whole width of the track should be laid on a concrete foundation, and where damp subgrades exist the concrete should be reinforced. It is moreover advantageous under such conditions to continue the concrete to the kerb of the road, in order to eliminate the possibility of a longitudinal joint adjoining the margin.

The most suitable forms of paving for tram tracks are :—

1. Non-slip granite setts of 5 to 6 in. depth. These should be laid adjoining the rails, clear of the flange.

2. Wood-block paving. This forms a fairly satisfactory surface for easy gradients and has a silencing effect on the noise usually present with tramway traffic.

3. Bituminous asphalte laid upon concrete is suitable for quiet thoroughfares, but not suitable for heavy traffic, which causes the asphalte to creep away from the rail to the channel, thus causing a longitudinal ridge and hollow. Other forms of paving, such as grit setts and tar macadam with one row of granite setts adjoining the rails, have been used, but generally speaking they are unsatisfactory. There is little experience of concrete paving on tram tracks in this country, though it is being used to an increasing extent in America ; it has, however, been laid with success in

Foregate Street, Chester, where conditions were unfavourable. Care must be taken that the rails are absolutely rigid and that the concrete is well packed against them ; also that tram traffic is stopped if possible until the concrete has set reasonably hard.

The grooving which is so troublesome alongside tram rails has been prevented in Glasgow and elsewhere by introducing cast-iron setts or blocks at intervals, or by laying slabs of granite when the remaining paving is of wood or asphalte.

CHAPTER IX

THE construction of waterbound macadam is not a form of road-making which belongs to the present age of motor transport; in passing, however, it is perhaps preferable to mention briefly the construction of such roads, and also to allude to the methods of improving and strengthening them.

A good foundation is one of the first essentials for a water-bound macadam road : the area for the carriageway should be excavated to a depth of 16 to 18 in. below the finished surface line, cindered with 2 to 3 in. cinders, and then hand pitched with hard rock set on edge with the broadest side downwards 10 in. deep, in the manner of Telford construction (Fig. 49). The irregular

FIG. 49 – Section of Telford Road Construction.

corners of the stones should then be broken off and the interstices of the soling rock filled in with small stones, after which the material should be consolidated by steam-rolling until thoroughly compact. This foundation surface is then covered with a 3½-in. layer of 2½-in. gauge broken granite or other stone as the case may be, and rolled with chippings of the same rock and water-binding until fully consolidated, after which the finished layer of 2 to 3 in. is put down and rolled in the same manner. The amount of water used affects the final result, and care should be exercised in order not to use an excessive quantity.

Kerbing and channelling are of vital importance in strengthening the macadam at its weakest point, viz. the edges. It is common

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practice to lay two or three rows of grit setts to form the channels either with or without kerb : this practice has been pursued too long. In the case of wider roads the full thrust at the channels is only felt where there is an excessive camber, and in any event sett channelling. has practically no strength laterally, nor is it very clean or sanitary for surface drainage purposes.

Widening Macadam Roads with Concrete Channels.

The application of concrete in this connection is particularly valuable. A concrete channel 6 to 8 in. deep and 12 in. wide is much stronger than a sett channel 18 in. wide, and incidentally is very much cheaper in its inital cost, but a concrete channel 2 or 3 ft. wide will make a tremendous difference to the side support-ing value of a macadam, or indeed a bituminous road. More-over, these concrete strips or channels laid at each side of an unsupported macadam road, say 15 ft. wide, may very well increase the total effective width of carriageway to 21 ft. without seriously disturbing the existing macadam, except perhaps that in reducing the camber a little extra macadam or bituminous surfacing may be applied at the haunches. Examples of this method of road strengthening and widening are shown in Figs. 50, 51, and 52.

Tar-Spraying Waterbound Macadam.

The life of waterbound macadam is increased considerably by periodical applications of tar and chippings. Newly rolled macadam when dry is perhaps more suitable to receive a tar dressing than macadam which has been down a considerable time. In the former case, the hot tar will penetrate to a greater depth and the covering material may consist of finer chippings, say, $\frac{1}{4}$-in. granite and down to dust to prevent adhesion ; on the other hand, where the tar has not penetrated to any extent, it is necessary to apply a good coating of granite chippings, say, $\frac{3}{8}$-in. or $\frac{1}{2}$-in. screened, to take up the tar, so that the thickness of the coating is much greater than in the case of the new macadam. Figs. 53 and 54 illustrate this point. It is shown elsewhere that such coatings or carpets of tar and chippings have a decided tendency to work up into waves, and tar applications should be
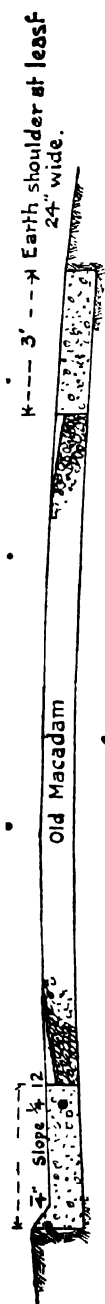
Fig. 50.—Typical Section of Macadam Road widened with Concrete Channels.
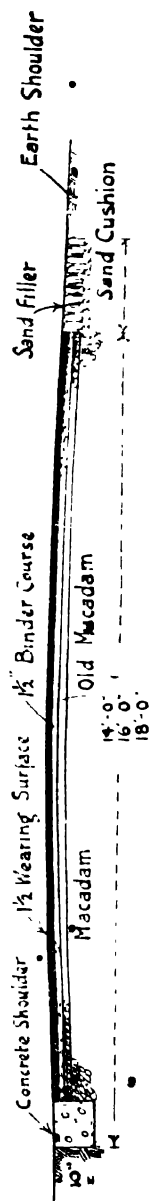
Fig. 51.—Section of Macadam Road Widened, Strengthened, and Re-surfaced.
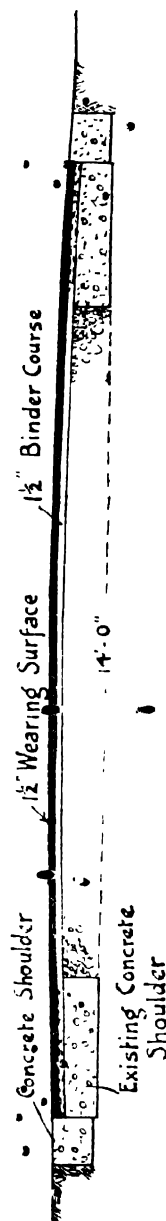
Fig. 52.—Section of Macadam Widened with Concrete Strips and Completely Re-surfaced with Bituminous Wearing Course.

given with great care and understanding. A great deal depends on the nature of the binding material used with the original macadam, and each case should be treated on its own merits.

Surfacing of Roads with Silicate of Soda.

Silicate of soda for re-surfacing of roads has been used in Locle, Switzerland, from 1918 with considerable success. The experiment has been carried out on seven roads by French engineers at Montbeliard. These roads had proved unsatisfactory with tar
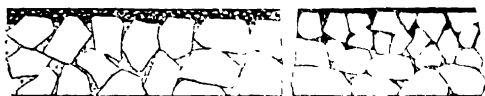
FIG. 53.—Relative Difference between Old Macadam and New Macadam after Tar-Spraying.

treatment owing partly to the damp subsoil. The altitude of the roads ranges from 300 to 900 m. (983 to 2950 ft.) and the sub-grades vary considerably.

The following proportions per cu. m. (1·09 cu. yd.) are used :—

0·35 cu. m. (0·38 cu. yd.) fine material.

40 litres silicate of soda (of 35° Beamé strength).

The stone is spread to the required thickness and the above mixture brushed into it as a matrix or binder. The surface is

FIG. 54.—Penetration of Macadam after further Tar-Spraying.

levelled and then rolled rapidly with a heavy roller until the surplus binding appears at the surface, after which considerable slow rolling is necessary. Chippings are then spread and the road closed to traffic for two days. The mixture and grading should be such as to eliminate all voids in the finished road.

A comparison of cost shows that the use of silicate of soda almost doubles the cost of waterbound macadam, but it is claimed that it is more economical than tar applications, which have to be renewed annually and sometimes twice annually.

Road Department Specifications

The following specifications for re-surfacing and also for surface tarring waterbound macadam roads were issued by the Road Board prior to the War :—

Re-surfacing.

These general directions are intended for use in cases where a new surface coating is to be laid with steam-rolled waterbound macadam on any road which has a proper foundation or sub-crust of adequate thickness.

Trial Trenches.

Before laying the new surface the thickness of the old crust, including the foundation, should be ascertained by opening trial trenches at intervals averaging about 150 yd. apart, extending from the side to the centre of the road, such trenches to be made alternately on opposite sides of the road. A careful record of the facts disclosed by these trenches should be kept with plans and sections for future reference.

If a proper foundation or sub-crust of adequate thickness does not exist, or if the road is weak at the haunches, the following steps should be taken.

In the case of heavily trafficked roads the haunches should be strengthened and the crust thickened either with stone of any kind suitable for bottoming work, broken to a gauge of from three to four inches, or with hard core, clinkers, or other suitable materials, according to the nature of the subsoil. In some cases, where the surface of the broken stone, after being steam-rolled, is sufficiently smooth for the purpose of traffic, it may be possible to allow the bottoming material to be used as the wearing surface of the road for a short period, not exceeding 12 months, if it is important for financial reasons to postpone for that period the laying down of the final surface coating in accordance with the other provisions contained in these general directions.

Total Thickness of Crust.

Even when there exists a good natural foundation, the total thickness of the road crust, including the old and the new macadam, after consolidation by rolling, should not be less than 4 in. In the case of well-drained subsoil, which cannot be materially softened by the infiltration of surface water, the total thickness, including the new consolidated surface coating, as well as the subcrust and foundations, if any, should not under ordinary circumstances be less than 5 in. In the case of fairly hard clay or other yielding

subsoils, the total thickness, including foundations should not be less than 9 in. In the case of soft wet clay or bog or marshy subsoil, foundations of a special character may be required.

Thickness of New Surface Coating.

The thickness of the new surface coating of macadam when consolidated by rolling should be from 2 to 3 in., according to the traffic requirements. If it is desired that the new coating should have a greater thickness than 3 in. when consolidated, the stone should be applied in two coatings separately rolled.

Cross-fall.

The finished surface should have a cross-fall of 1 in 24, or $\frac{1}{2}$ in. to the foot. If the old crust is not sufficiently thick at the crown to enable the cross-fall to be obtained when a new coating of the thickness above-mentioned is superadded, the old surface should be left intact and unscarified, and the thickness of the new coating of macadam should be increased as far as may be necessary. If the crust is of ample thickness, but the cross-fall excessive; it should be reduced by scarifying the surface and removing material from the crown to the sides previous to the application of the new coating. The material so loosened by scarifying should be screened, and all material finer than $\frac{1}{2}$ in. should be put on one side to be used for top dressing during rolling operations.

Stone and Screenings.

The road stone for the new surface coating should be stone of approved quality, broken as cubically as possible, and should contain about 70 per cent of stone which should pass through a $2\frac{1}{2}$-in. ring, but which will not pass through a $1\frac{3}{4}$-in. ring ; about 20 per cent which will pass through a $1\frac{3}{4}$-in. ring, but which will not pass through a screen with rods $\frac{3}{4}$ in. apart. The screenings forming the residue from the above, which will be obtained by the use of the $\frac{3}{4}$-in. rod screen, should be kept separate and used as a top dressing during rolling operations.

Spreading.

The stone must be spread by careful men selected for their knowledge and, experience of such work, as the durability and evenness of wear of the surface obtained by steam-rolled coatings greatly depend on judicious uniform spreading. The whole of the stone should be turned over in the process. Care must be taken not to allow the stone to be tipped upon the road close to the point of spreading, as this prevents a thorough turning over of the material

in the act of spreading. When stones are transported by rail or by road over long distances the different sizes of stone are liable to separate themselves, and it is important that during the act of spreading they should be well mixed so as to obviate the possibility of having larger stones on some parts of the road and smaller stones on other parts.

Note.—One ton to cover 8 to 9 sq. yd. may be taken as an average quantity required to give a consolidated thickness of 3 in. When stones are spread in thick coatings so that 1 ton covers less than 8 yd., there is a greater liability to unequal consolidation, because stones are pushed in front of the roller until the roller surmounts them and thus a corrugated or wavy surface is formed.

Rolling.

The rolling should be carried out by a roller of a weight of about 10 tons. This must be in charge of a skilled driver who has been specially trained for the purpose. The macadam should be consolidated by starting the work at the sides and gradually working towards the centre. No water or binding should be applied until dry rolling has been carried out to a sufficient extent to form a smooth, hard surface with a correct cross-fall, with the stones well knit together and showing their faces on the surface. The cross-section of the newly rolled surface should be frequently checked by the use of a long straight-edge and level to ensure that the cross-fall of 1 in 24 is correctly obtained. No spreading or rolling should be carried out in frosty weather. When the road cannot be entirely closed to traffic, care should be taken to minimize inconvenience to the travelling public during the progress of the work by coating one-half the width at one time. No unrolled stone should be left on the road overnight. Care should be taken not to leave a vertical or steep edge of the new coating, but the edge should be thinned out so as to afford an easy passage from the new coating to the old surface. Notice boards warning the public that steam-rolling work is in progress should be placed at reasonable distances from each end of the work.

Binding.

The binding material should be the best obtainable. It should be either of the same material as the new coating, or of granite, limestone, or slag chippings, or failing these suitable pit sand or gravel, and the largest stone in it should not exceed ¾ in. in its greatest dimension. The binding material is not to be applied until the stones have been tightly rolled as above-described. It should then be spread, watered, and swept over the surface during the final

rolling operations, working it from the channels towards the centre so as to fill the interstices or voids between the rolled stones. Care should be taken not to use more binding material or water than is absolutely necessary to ensure proper consolidation. The success of waterbound steam-rolling so greatly depends on the quality and quantity of the binding material used that extreme care should be taken in its selection and application.

Rerolling.

In some cases it is advisable that a steam-rolled waterbound macadam surface should be lightly watered and rerolled from a week to a fortnight after the first rolling.

Records.

A careful daily record should be kept of all particulars of the work, the number of men employed, the time occupied, the quantity of material used, the area of new coating finished, also of the state of the weather and other details.

Road Board Specification No. 1
General Directions for Surface Tarring on Waterbound Road.

1. Surface tarring may be advantageously applied either to an old road surface in good condition or to a new surface after it has been consolidated and dried, but the tarring should never be carried out unless the road is thoroughly dry.

If there are any depressions, potholes, waves, grooves, or other irregularities, these should as far as practicable be made good before tarring is commenced, so as to provide an even surface.

2. Painting and spraying machines get through the work of tarring more rapidly than application by hand, and consequently are to be recommended, but hand work gives satisfactory results, and the selection of the method to be employed must be largely determined by the available supply of efficient labour.

3. If it is intended to tar an old surface it is advisable to take advantage of the early months of the year to scrape or brush the road during wet weather as a preparation for subsequent tarring, and especially to keep the road free from caked mud.

4. If the crust of a road is thin at the sides, but adequate in the centre, the sides should be strengthened and consolidated before application of tar to the surface.

5. In re-surfacing any road the surface of which is afterwards to

be tarred, stone chippings, and not fine material, should be used for binding.

6. The road whilst being tarred should be closed to traffic over half its width, or, where practicable, over its whole width.

7. The road should be thoroughly brushed and cleaned before application of the tar. Wet brushing should be used some time previous to dry brushing, if there is any caked mud. Any method of brushing may be used which will scour and clean the road thoroughly, the best being horse brushing, followed by hand brushing.

8. Tar should be used for surface tarring which complies with the Road Department Specification for Tar No. 1.

9. The tar should be heated to its boiling-point at convenient positions on the works, and should be applied as hot as possible, so that it may flow freely. The tar should be heated in a heater or "boiler" especially designed to prevent frothing, which will otherwise inevitably occur if the tar contains even a small percentage of water. The desired temperature will be generally found in practice to lie between 220° and 240° Fahrenheit for Tar No. 1 and between 260° and 280° Fahrenheit for Tar No. 2.

10. In order that the tar should be applied to the road as hot as possible, it is advisable, if the method of application is by hand, to use flexible pipes to convey the tar from the boiler to the point of application. If these are not available, it will be found convenient, in case of hand pouring, to use 3-gallon cans specially constructed for the purpose, fitted with spouts leading direct from the bottom of the cans, and being not less than $1\frac{1}{2}$ in. in diameter at the orifice.

11. Immediately on application the liquid tar should be brushed so far as necessary to ensure regularity in thickness of the coating.

12. The quantity of tar required will vary according to the physical conditions of the road, but generally, in the case of a road to be treated with tar for the first time, the quantity should be one gallon to coat from five to seven superficial yards.

13. If the road must be opened for traffic before the tar has set hard, grit should be spread on the surface to prevent the tar from adhering to the wheels of vehicles, but gritting should be delayed as long as possible, and the quantity of gritting material to be spread should be no more than sufficient to prevent the tar from adhering to wheels. Stone chippings, crushed gravel, coarse sand, or other approved material (free from dust) not larger than will pass through a $\frac{1}{4}$-in. square mesh should be used for gritting.

14. Precautions should be taken to prevent liquid tar passing directly through drainage gratings or outlets.

15. For the safety of the public precautions should be taken by lighting, watching, and warning.

Notice boards should be placed in suitable positions bearing in large letters printed in conspicuous colours the following words :—

CAUTION.

Tarring in Progress.

Cyclists advised to walk.

It is specially desirable to place warning notices at points in the neighbourhood of the work where other roads join or cross the road being tarred, to enable motorists and cyclists to avoid the obstructed road by taking any available alternative route.

16. On heavily trafficked roads it is advisable to apply a second coat to either the whole width or from 9 to 12 ft. of the centre of the road in quantity of one gallon to coat from 8 to 10 yards super., about two to three months after the first application.

17. Surface tarring should be renewed annually on all important roads, and as required on roads with light traffic. On such re-coatings the quantity of tar to be applied will vary with the extent to which the previous coating of tar has been removed by weather, or by traffic.

18. Two or more samples of the tar used should in all cases be kept in half-gallon tin cans, and be carefully labelled, including particulars fixing the locality or length of the road on which the tar was used. The Road Department will arrange with the National Physical Laboratory to submit a selection of these samples to a series of chemical and physical tests with a view to the results being recorded for future reference, and surveyors will from time to time be invited to send samples for the purpose.

19. In all cases careful record should be kept of the condition of the road surfaces in winter and summer, both before and after tarring, the quantity and quality of tar used, the superficial area covered, the state of the weather when the work is being done, the time occupied in actual work, and in waiting whilst work is stopped owing to wet weather, the number of men employed, and full details of the cost of labour and material.

20. Surveyors are recommended to have samples of the tar supplied to them under contracts properly tested by a qualified analytical chemist, and the results given on the standard form, a specimen of which will be found on page 260.

Note.—These general directions are not intended to displace or to discourage the use of proprietary articles, but no proprietary article should be used for surface tarring which contains more water, naphthalene, or phenols than is specified in the Roads Department Specification for Tar No. 1, while the " free carbon " with any alternative or " additional filler " should not exceed the limit specified for " free carbon."
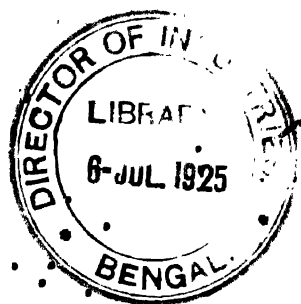
CHAPTER X

BITUMINOUS AND TARRED ROADS

BITUMINOUS road surfaces are of many types, the essential feature of each being the use of bituminous matrices. It has been customary in the past to include under the heading of bituminous material tar and pitch residue from oils with a bituminous base. The British Engineering Standards Committee on bitumen has defined the term " bitumen " to cover only materials essentially resilient in character, soluble in carbon-disulphide (CS_2), and obtained only from distillations of earth oils or ground asphalte. This definition does not include tar products.

Without this discrimination the advantages of bituminous surfaces over waterbound macadam are :—

1. Imperviousness.
2. Ease of maintenance.
3. Facility for repairs.
4. Smooth surface.
5. Noiselessness.
6. Dustlessness.

The disadvantages may be stated thus :—

1. Unsuitability for steep gradients.
2. Difficulty in securing uniformity in material and a consequent uneven tractive resistance.
3. Tendency to corrugate.

The use of blast-furnace slag broken to suitable sizes, tar treated while hot or reheated and then coated with tar, was one of the earliest methods of tarred road construction in this country.

The tarred material was spread and rolled in successive layers, using the coarser material for the lower layer and the finer

material at the top. This tarred slag macadam was economical in construction, easy to maintain, and, on the whole, the roads laid in this manner have proved to be very successful.

Pitch-Grouted Macadam, Road Department Specification

Prior to the War the Road Board, now the Ministry of Transport, issued general directions for surfacing roads with pitch-grouted macadam as follows :—

1. Any road which is so surfaced with pitch-grouted macadam. should have a proper foundation or sub-crust of adequate thickness.

2. Before laying a new surface of pitch-grouted macadam the thickness of the old crust should be ascertained by opening trial trenches at intervals averaging about 150 yd , extending from the haunch to the centre, such trenches to be made alternately at opposite sides of the road.

3. The thickness of the surface coating of pitch-grouted macadam when finished and consolidated by rolling should be $2\frac{1}{2}$ to 3 in., except on very light traffic roads, when the thickness may be 2 in. for single pitch grouting and from 4 to $4\frac{1}{2}$ in. for the double pitch grouting hereafter described.

4. In the case of naturally hard subsoils, not materially softened by infiltration of surface water, the total thickness of the road crust, including foundation, if any, after consolidation by rolling of the new pitch-grouted surface, should not under ordinary circumstances be less than 6 in., unless the subsoil be sufficiently hard in itself to act as a foundation, in which case the thickness of the road crust may be reduced to 4 in. In the case of clay or other yielding subsoils the total thickness should not be less than 11 in.

5. The finished surface should have a cross-fall of about 1 in 32. If the crust is not sufficiently thick at the crown to enable this cross-fall to be obtained with a new coating of the thickness above-mentioned, then the old surface should be left intact and unscarified and the thickness of the old pitch-grouted coating increased as far as may be necessary. If the crust is of sufficient thickness for the purpose, the regulation of the cross-fall should be carried out by scarifying the surface and removing material from the crown to the sides previous to the application of the new coating. Material loosened by scarifying should be screened and all material finer than $\frac{1}{2}$ in. should be thrown aside.

6. The aggregate of broken stone to form the new surface of pitch-grouted macadam should contain broken stone of approved quality of which at least 60 per cent must be broken to the size of

$2\frac{1}{2}$ in. and 35 per cent to sizes graded from $2\frac{1}{2}$ to $1\frac{1}{4}$ in. In addition to this 5 per cent of chippings of the stone, varying from $\frac{3}{4}$ down to $\frac{3}{8}$ in., should be used for closing after the grouting with melted pitch.

7. For making pitch-grouted macadam the pitch should comply with the Road Board Specification for pitch, its viscosity being altered to suit the climatic and local conditions, by varying the quantity of oils as specified therein.

8. It is important that the pitch should not be poured if the surface of the stone is wet. The stone may be protected by tarpaulins, or, if wet, may be dried in situ by portable blowers or other means.

9. The quantity of pitch required to grout a single coating is approximately, for a consolidated thickness of 2 in., $1\frac{1}{4}$ gal. per yd. super., for $2\frac{1}{2}$ in.. $1\frac{1}{2}$ gal. per yd. super., and for 3 in., 2 gal. per yd. super., but these quantities may vary with different materials, and care must be taken to fill the voids adequately.

10. The aggregate after having been spread and levelled must be rolled down dry until the surface is formed, but without the addition of any small material.

11. The pitch, after having been carefully melted, must be raised to a temperature of 149° C. (300° F.). Clean, sharp sand must be heated on sand heaters to a temperature of 204° C. (400° F.). A dandy or portable mixing vessel is then to be filled with equal parts by measurement of the heated pitch and hot sand. and the mixture, hereafter called the matrix, is to be kept well stirred while it is being emptied from the dandy into pouring cans of from 2 to 3 gallons capacity, which are used for pouring the matrix on to the roadway. Not only during the process of mixing, but afterwards right up to the time of actual pouring, the matrix must be kept well stirred.

12. The final rolling should be commenced immediately after pouring the pitch matrix, and carried on rapidly before the matrix has time to set. The 5 per cent of graded chippings should be spread over the grouted surface in part previously to, and the remainder during the process of rolling. The traffic may be allowed on to finished surface as soon as it has cooled to the normal temperature.

Double Pitch Grouting.

13. When the traffic is so heavy that a consolidated thickness of from 4 to $4\frac{1}{2}$ in. of pitch-grouted macadam is required, it is desirable, in order to obtain the best and most economical results, to divide the coating into two layers, the bottom layer to be the thicker one, and to consist of large stones, the two layers to be rolled down and grouted separately. Any local stone that can be procured cheaply

may, if suitable for foundation work, be used for the bottom layer graded from 3 in. down to 2 in. gauge. No chippings are required for finishing the bottom layer. The aggregate for the upper layer should consist of hard road stone of approved wearing quality, broken to 1½ in. gauge, and 5 per cent of chippings of the same stone used for the upper layer graded from ½ in. down to ¼ in. should be added, before and during the process of rolling, and rolled down so as to form the finished surface of the road.

14. In pouring pitch on the bottom layer the surface of the pitch should not be brought to the surface of the stone, but should lie about ½ in. below such surface, with the object of providing a key for the upper layer.

15. The materials and the method of grouting and laying down in the case of double pitch grouting should, except when otherwise expressly stated, conform to the provisions of clauses 7, 8, 10, 11, and 12.

16. The quantity of pitch required for double pitch grouting is approximately for a consolidated thickness of 4 in., 3¼ gal. per yd. super., and for 4½ in., 3½ gal. per yd. super.

17. All materials used in the preparation of the matrix should be accurately proportioned by weight or measurement.

Instructions for Melting the Pitch.

The pitch boilers of from 2 to 3 tons capacity should be charged with pitch and about one-half of the proper proportion of tar oils. The fire should then be lighted, and thereafter a steady fire with fire doors closed should be maintained, when, in from 4 to 5 hours, the pitch should be thoroughly melted. A bright fire should be kept until the pitch reaches a temperature of 149° C. (300° F.), when the remainder of the oils should be added and the mixture thoroughly stirred ; the fire doors should then be opened and the temperature of the melted pitch permitted to fall to 121° or 132° C. (250° or 270° F.). The pitch should then be ready for use, and in all cases should be thoroughly stirred before being drawn off. In the event of bad weather stopping the grouting the fire door should be left open, the damper closed, and the temperature of the pitch allowed to fall to 93° C. (200° F.). It can be kept at this temperature for long periods with banked fires consuming about 7 lb. of coke per hour.' It is recommended that a suitable Fahrenheit thermometer with metal protection should be at hand to indicate the temperature of the melted pitch. Whenever the weather is favourable for the recommencement of the work the pitch must be again raised to 132° C. (270° F.) by closing the doors and sharp firing. It is desirable that the boiler should be kept airtight when the pitch is being melted,

by the use of airtight covers properly packed so as to make an air-tight joint.

Occurrence of Bitumen.

Geographically bitumen is widely distributed over the globe :

1. In the form of natural gas.
2. In liquid form as petroleum.
3. In heavier form as native solid bitumen in Venezuela, Cuba, Trinidad, and Mexico, etc.

Chemically, bitumen belongs to a group of substances, hydro-carbons, and almost invariably it includes a lesser amount of sulphur, oxygen, and nitrogen, all of which are soluble in carbon-disulphide.

Oil residual bitumens are derived from the industrial distillation of petroleum, principally in Mexico, Texas, California, etc.

Natural rock asphalte was discovered in the early part of the seventeenth century in Neuchâtel in Switzerland ; it consists of limestone impregnated with bitumen. There are other continental deposits in Sicily, France, etc.

Trinidad asphalte is perhaps the best-known and most exten-sively used of native asphaltes. It is obtained from the famous (so-called) pitch lake which covers an area of 114 acres. It has a maximum depth of solid bitumen of about 135 ft. and is esti-mated to contain 9,000,000 tons of bitumen. The material in its crude form, i.e. as dug from the lake, has the following average composition : —

Volatile at 212° F.	29%
Bitumen soluble in CS_2	39%
Mineral matter (ash)	27·5%
Organic matter insoluble	4·5%
	100·0%

The process of refining, which consists of driving off the water by means of tanks heated with steam coils at a pressure of

125 lb., giving a temperature of 325° F., results in a product of the following composition and properties :—

Bitumen soluble in CS_2 . . . . 56·5%
Mineral matter (ash) . . . . . 38·5%
Organic matter, insoluble . . . . 5·0%
                                          ——————
                                          100·0%

Specific gravity at 60° F. indicating density . 1·40
Softening-point . . . . . . 180° F.
Flowing-point . . . . . . 235° F.
Penetration at 77° F. by needle of penetrometer   4°

A suitable oil medium for softening the bitumen has the following properties :—

Specific gravity at 60° F. . . . . 0·92–93
Flash-point . . . . . . 350° F.
Volatile in 7 hours at 325° F. . . not more than 5%

About two hours' agitation of bitumen and oil mixture by means of air pumps at a temperature of 320° F. results in a homogeneous cement which shows the following analysis :—

Bitumen soluble in CS_2 . . . . 67·0%
Mineral matter (ash) . . . . . 28·5%
Organic matter, insoluble . . . . 4·5%
                                          ——————
                                          100·0%

Specific gravity at 60° F. . . . . 1·27
Penetration at 77° F. . . . . . 60°

Before proceeding to deal with the different types of bituminous roads it is proposed to give the principal physical and chemical tests applied to bitumen.

Tests of Bituminous Material.

Specific Gravity.

As the weight of a given volume of material varies with different temperatures, the temperature basis of comparison should always be indicated for very accurate work. Where a sufficient quantity of material is available the specific gravity of bituminous materials can be conveniently ascertained with a hydrometer.

Melting-point.

The cube method and the ring and ball method are the two most commonly used in road engineering.

In the former test the material to be examined is first melted in a spoon until sufficiently fluid to pour readily. It is then poured into a 0·5-in. brass cubical mould which has been amalgamated with mercury and which is placed on an amalgamated brass plate. The hot material should slightly more than fill the mould, the excess to be cut off with a spatula. After cooling to room temperature, the cube is removed from the mould and fastened upon the lower arm of a No. 12 wire, bent at right angles and suspended beside a thermometer in a covered Jena glass beaker of 400 cu. cm. capacity, which is placed in a water bath, or for high temperatures, cotton-seed oil. The wire should be passed through the centre of two opposite faces of the cube, which is suspended with its base 1 in. above the bottom of the beaker. The water or oil bath consists of an 800 c.c. low form

FIG. 55.—Melting-point Apparatus for Cube Method.

Jena glass beaker, suitably mounted for the application of heat from below, as shown in Fig. 55. The beaker in which the cube is suspended is of the tall form Jena glass type without lip. The metal cover has two openings. A cork, through which passes the upper arm of the wire, is inserted in one hole and the thermometer in the other. The bulb of the thermometer should be just level with the cube and at an equal distance from the side of the beaker.

In order that a reading of the thermometer may be made, if necessary, at the point which passes through the cover, the hole is made triangular in shape and covered with an ordinary object glass through which the stem of the thermometer may be seen. Readings through this glass should be calibrated to the angle of

observation, which may be made constant by always sighting from the front edge of the opening to any given point on the stem of the thermometer below the cover.

After the test specimen has been placed in the apparatus, the liquid in the outer vessel is heated in such a manner that the thermometer registers an increase of 5° C. (9° F.) per min. The temperature at which the bituminous material touches a piece of paper placed in the bottom of the beaker is taken as the melting-point. At the beginning of this test the temperature of both the bitumen and the bath should be approximately 25° C. (77° F.).

Ring and Ball Test.

Melt the sample of material and fill a brass ring ⅝ in. in diam., ¼ in. deep, and with a ³⁄₃₂ in. wall, and remove any excess with a hot
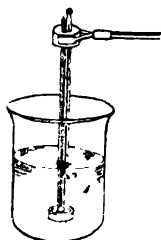
FIG. 56.—Melting-point Apparatus
for Ring and Ball Test.
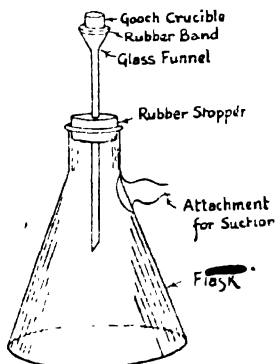
FIG. 57.—Apparatus for
Solubility Test.

spatula. Place a steel ball ⅜ in. in diam., weighing between 3·45 and 3·50 grms., in the centre of the ring and suspend in a beaker containing approximately 400 cu. cm. of water at a temperature of 5° C. (41° F.), as shown in Fig. 56. Arrange thermometer bulb within ¼ in. of sample and at same level. Apply heat uniformly over the bottom of the beaker in quantity sufficient to raise temperature 5° C. (9° F.) per min. Record temperature at commencement of the test and every minute after until completion. The rate of heating is very important. The softening-point is the temperature at which specimen has dropped 1 in. For temperatures above 95° C. (203° F.) glycerine should be used instead of water. High melting-point materials are, as a rule, less susceptible to the ordinary temperature changes than are low melting-point products ; they are, therefore, more satisfactory in use either as a seal coat or as a filler.

Solubility.

This test is of special value when made on the mixed material to be used on the road, as it shows the amount of binding material present. Its object is to determine the percentage of the sample that will dissolve in carbon-disulphide. The apparatus consists of a Gooch crucible, as shown in Fig. 57, fitted on to a filtering flask by means of filter funnel and rubber band. The crucible is filled with suspended asbestos, the water from which is afterwards drawn off, leaving a mat of asbestos in the crucible ; this process is repeated until a firm mat is formed and then the crucible is dried and weighed. Some 2 to 3 grms. of bituminous material is dissolved in a weighed flask containing 100 c.c. of carbon-disulphide. After about 15 mins. the solution is decanted through the asbestos mat without suction, and afterwards the precipitate is passed on to the felt in the crucible, being washed several times and then suction applied. It is then dried and weighed and the amount of bitumen found by difference. The insoluble matter may contain organic matter and this is found by ignition.

Coefficient of Expansion.

In the case of bitumens the normal temperature is taken as 25° C. (77° F.). As a material expands under the action of heat, the specific gravity becomes less. In consequence of this, it is possible to calculate the coefficient of expansion by taking volume measurements at different temperatures.

The fluid bitumen is poured into a dilatometer, which is calibrated at normal temperature so that when filled to any mark on the graduated neck its contents are known. The dilatometer and contents are placed in a carefully regulated oven and heated. When the temperature is uniform the position of the meniscus is read, compared with the original position, a correction is made for the coefficient of the glass, and the coefficient of the bitumen can then be ascertained by means of the following formula :—

$$K = \frac{V' - V}{V(t' - t)},$$

where V represents the volume at normal temperature, V' the actual volume at the observed temperature, t normal temperature, and t° the observed temperature.

The volume method can only be used successfully for solid bitumens ; for semi-solids the specific gravity method is more satisfactory.

The specific gravity of a given quantity of bitumen is first ascertained by means of a pycnometer, and the weight of the water contents of the pycnometer at any desired elevated temperature is

then obtained and another specific gravity determination made of the material at this elevated temperature as compared with water at the same temperature. From the known value of K for water, which is about 0·0002 per °C., the specific gravity of the material at the elevated temperature is then determined as compared with water at normal temperature. The coefficient of expansion is then determined by means of the following formula :—

When G represents the specific gravity at normal temperature t
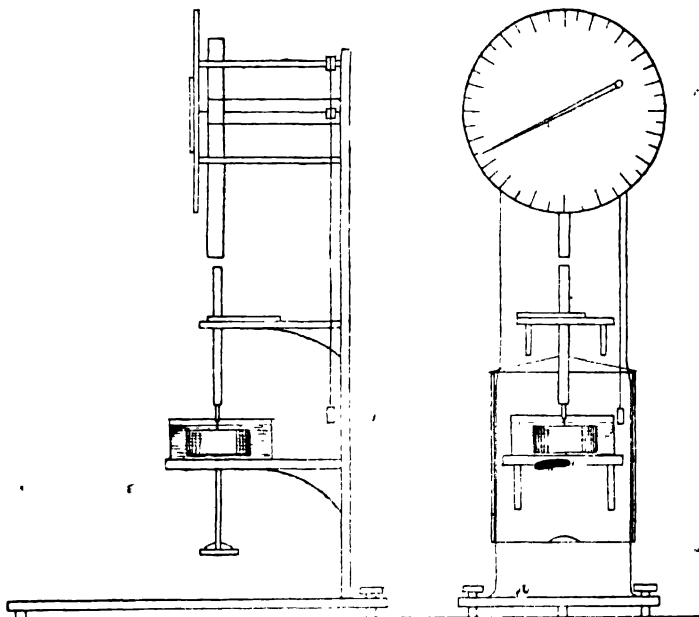
Fig. 58.--Penetrometer for Penetration Test.

and G′ represents the specific gravity on the same basis at the observed temperature t' :—

$$K = \frac{G - G'}{G'(t' - t)}.$$

When bitumen is purchased upon a volume basis, the practical value of the knowledge of the coefficient of expansion is obvious.

Fixed Carbon.

This test is taken from Bulletin No. 38, Bureau of Public Roads, U.S.A. A gram of bitumen is placed in a platinum crucible having a tightly fitting cover. This is heated, first gently and then more

violently until no smoke or flame issues from the crucible. It is then heated in the full heat of the bunsen burner to drive off the most volatile products, cooled and weighed, and then ignited over a bunsen burner until only ash remains. It is again weighed and the difference in weight represents the fixed carbon in the original material.

Penetration.

This test consists in applying a weighted needle to the sample and measuring the distance it penetrates in a given short space of time, as shown in Fig. 58. The sample is maintained at 25° C. (77° F.) by keeping it in an open tin box which is covered with water. By means of this test the right degree of hardness can be ensured, and the consistency and uniformity can to a certain extent, be regulated.

Viscosity.

The apparatus used in this test is an aluminium float and a conical brass collar (Fig. 59). A small quantity to be tested is heated in a metal spoon until quite fluid, then poured into the collar until slightly more than level with the top. The surplus is removed with a warm spatula. The collar and plate on which it rests are then placed in ice water maintained at 5° C. (41° F.) and left for 15 mins. Sufficient water is heated to the temperature desired, and the collar and contents are screwed into the aluminium float which is floated in the warm bath. As the specimen becomes

FIG. 59.—Float Test for Viscosity.

fluid it is forced upwards and out of the collar until water gains entrance to the saucer, which then sinks. The time between placing the apparatus and when the water breaks through is taken as the viscosity. This test is useful for materials too soft for the penetration test.

Ductility.

The ductility test consists in moulding a briquet of the material 3 cm. by 1 cm. by 2 cm., which has been kept in water at a temperature of either 39° F. or 77° F. It is then placed in a ductility test

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machine filled with water. Clips are attached to the briquet, and after 30 mins. power is applied by means of a worm-gear pulling from right to left, at a uniform rate of 5 cm. per min. The distance registered at the time of rupture is the ductility of bitumen.

Other tests are flash-point determination, volatilization tests, distillation tests. etc.

Brief Specification for Aggregate for Bituminous Work

The following is given as a guide for up bituminous specifications.

General.

"The broken stone shall consist of angular fragments of rock, excluding schist, shale and slate, of uniform quality throughout, free from thin or elongated pieces, soft or disintegrated stone, dirt or other objectional matter occurring either free or as a coating on the stone."

Physical Properties.

"The stone shall meet the following requirements : French coefficient of wear (see Chapter XV) not less than 7. (Toughness, Hardness, and Absorption may be added if desired.)"

Chippings or Fine Material.

"That portion of the product of the crusher which, when tested by means of laboratory screens, will meet the following requirements :—

Passing 1-in. screen, not less than . . .	95%
Retained on ¼-in. screen, not less than . .	85% "

Coarse Stone.

"That product of the crusher which, when tested by means of laboratory screens, will meet the following requirements :—

Passing 2-in. screen, not less than . . .	95%
(reject all over 2½ in.)	
Total passing 1½-in. screen	25 to 75%
Retained on 1-in. screen, not less than .	85% "

Specifications for Bituminous Cement

The following points, or so many of them as are applicable or desirable to secure uniformity of product, are usually covered by the specifications :—

1. Homogeneity.

" The asphalte cement (refined) shall be homogeneous and shall not foam when heated to 177° C."

2. Specific Gravity.

"" Usually taken at 25° C. (77° F.) for both substance and water. 1·000 to 1·045."

3. Melting-point.

Method to be stated—cube or ring and ball.

4. Flash-point.

" Not less than 205° C."

5. Consistency.

The penetration method is ordinarily used for asphaltes and viscosimeter and float methods for soft asphaltes, tars, and petroleum oils. Temperatures are specified for which the tests shall be made.

6. Volatility.

" Loss by distillation at 163° C. for 5 hours not over 2 per cent." The penetration and specific gravity of the residue are also specified.

7. Solubility.

(A) Carbon-disulphide. " The total bitumen soluble in carbon-disulphide shall be not less than 90 to 99 per cent.

(a) Organic matter insoluble, not over   per cent.

(b) Inorganic matter insoluble,   per cent to   per cent."

(B) Carbon tetrachloride, "   per cent soluble in."

(C) Paraffin naphtha, "   per cent insoluble in 86° B naphtha.
     to   ."

8. Fixed Carbon.

"   per cent to   per cent."

9. Ductility.

"   ° C. not less than   centimetres."

Occasionally other tests may be specified. Where percentages are filled in these may be varied slightly by the engineer.

The various types of bituminous roads are :—

1. Bituminous macadam.
2. Sheet asphalte.
3. Rock asphalte.
4. Bituminous concrete.

Bituminous Macadam.

This is defined as a wearing course of macadam surfacing, the interstices of which are filled by penetration method with a bituminous binder. It corresponds to tar-grouted macadam.

The aggregate required for this type of pavement is similar to that used in the construction of the ordinary waterbound macadam road. Generally, it will consist of broken stone graded from 1 to ¼ in. and sand or chippings graded from ¼ in. downwards. The coarse material should be laid on a well-drained foundation, with uniformity, in order to ensure even tractive resistance on the finished road. The foundation course should consist of about 6 to 8 in. coarse stone well rolled with screenings, and the wearing course from 2 to 3 in. of 1 to ¼ in. stone graded and covered with a layer of about 15 per cent of sand or chippings which are swept in and rolled. The hot bituminous cement in the proportion of 1 to 2 gal. per sq. yd. is applied to the rolled stone, which must be thoroughly dry and preferably warm. It is necessary that the bituminous material be uniformly distributed, and that it penetrates to a depth of 2 to 3 in. In some cases a sealing coat may be applied, consisting of a thin coating of hot bituminous liquor, covered lightly with fine chippings to take the excess of bitumen, after which it may be again rolled.

Sheet Asphalte.

This material is often called bituminous macadam ; it consists of two courses laid on a foundation of old macadam or concrete. These courses are :—

1. A binder course, composed of bituminous or tar cement, broken stone, and sand.

2. A wearing course, composed of sand, fine chippings, aggregate, filler, and bituminous cement.

The aggregate for the binder course is heated by means of continuous dryers to 250° F. and after storage in bins on the mixing platform it is allowed to fall by gravity into a steel measuring box of, say, 7·5 cu. ft. capacity. The necessary quantity of bitumen is ladled from tanks into a travelling bucket. The aggregate is then tipped into one of the various types of mixers, which are generally fitted with a double shaft carrying paddle-shaped blades. About 5 gal. of bitumen is sufficient to coat 7·5 cu. ft. of aggregate.

The aggregate with the hot bitumen is mixed for about 1 to 2 min., according to speed of mixer; it is then ready to be conveyed to the site of the work. Much the same process is followed in the case of the wearing surface. The sand is passed through the same process of heating and drying, with the exception that the temperature is raised to about 400° F.

The same measurement of aggregate as in the binder, i.e. 7·5 cu. ft., may be taken, and after being shot into the mixer there is added about 14 per cent by weight of impalpable filler, such as limestone. In the case of the asphalte wearing surface about 15 gal. of bitumen is necessary to coat 7·5 cu. ft. of sand of standard grading. The mixture is usually hauled in motor trucks at a temperature of 320° F.

The following analysis represents a typical surface mixture :—

Bitumen soluble in CS_2	.	.	.	12%
Aggregate (including filler) passing 200 mesh	.	16%
,,	,,	,,	100 ,, .	12%
,,	,,	,,	80 ,, .	10%
,,	,,	,,	50 ,, .	40%
,,	,,	,,	40 ,, .	4%
,,	,,	,,	30 ,, .	3%
,,	,,	,,	20 ,, .	2%
,,	,,	,,	10 ,, .	1%
				100%

Asphalte mixtures of suitable density have the valuable property of retaining their temperature for 5 or 6 hours. The effect of this is that the work can be carried out from a central mixing plant effectively within a radius of 20 miles. On arrival, the mixture is easily unloaded by forks and shovels, assisted by tipping gear, and after being raked to the required thickness and to suitable contours, compression is applied by steam-rollers of from 5 to 10 tons in weight—the finished pavement being avail-
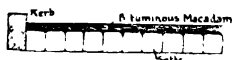
FIG. 60.—Bituminous Surfacing laid
on existing Sett Paving.

able for traffic after 5 hours, if the atmospheric conditions are good. Tandem steam-rollers are very suitable for this work, as they have a quick reverse motion, and in any case rapid. rolling is essential. For large works a portable plant would no doubt be employed in preference to haulage from the central plant.

The foundation course may be either of concrete or of the non-rigid type : the non-rigid or flexible base is usually expensive to
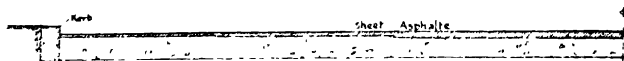
FIG. 61.—Section showing Stepped Concrete Foundation to Prevent
Creep and Reduce Thickness of Asphalte near Channels.

construct to obtain sufficient strength, although existing road materials may often be left in to advantage. Where cracks develop in the road surface it is frequently due to the cracking of the concrete base. The smooth rigid base is conducive to creeping and cracking of the wearing course under the action of the traffic. The provision of wood strips, 3 by 2 in. or 4 by 2 in., which should be nailed into the concrete base when green, may assist in preventing this, but it may also cause corrugation : otherwise concrete should be scored with deep marks, diagonally or transversely. When laid on old sett paving (Fig. 60) the joints may be cleaned out to a depth of 1 to 2 in., so that the asphaltic

material is " keyed " into the foundation and its movement under traffic largely prevented.

As a means of preventing transverse creep and also of effecting economy, the thickness of the asphalte may be reduced by stepping-up the concrete surface as shown in Fig. 61. This provides the greatest thickness where the wear is greatest, and the least thickness where traffic is at a minimum.

Sharp or Round Grains.

It is difficult to estimate the exact difference between round and angular particles of sand. In the case of the finer particles it is far more important to have a well-balanced grading than to aim at obtaining sharp sand. Round particles produce less voids than sharp particles and therefore give a denser mixture. The proviso " sharp sand " might very safely be omitted from specifications.

Voids.

It is generally understood that the success of asphalte depends on its being practically voidless and therefore dense. This is true up to a certain point, but it is quite possible to obtain a good wearing surface when voids are present, although there is obviously a liability for corrugation to be set up. An excess of bitumen may also occur simultaneously with the presence of voids. Voidage is often increased by the addition of very fine aggregate or dust unless the bitumen content is carefully regulated in the mixture. The combinations of the different aggregates vary, and the correct proportion of bitumen is difficult to determine ; to ensure correct mixtures as far as possible, frequent tests should be carried out.

In computing surface area the grains of aggregate are assumed to be either cubes, spheres, or other shapes relative to the mean diameter. The area of each grain varies as the volume ^{2}, and the total area of volume passing each sieve varies as $\dfrac{1}{\text{diam.}}$.

Sands of identical sieve analysis show a dry loose void percentage varying from 40 to 50 per cent. The aggregate passing a

200 sieve is an impalpable dust, the surface area of which is out of all proportion to its bituminous requirements and is very different from material retained on a 200 sieve. There are many dissimilar aggregates having widely different bituminous requirements; each, however, has an equal fineness modulus, and this shows that the fineness modulus cannot be used for the determination of the amount of bitumen required. Experiments show that the amount of bitumen is proportioned by the percentage of aggregate passing the 80, 100, and 200 sieves. It is to be observed that a certain weight of bitumen to each cu. ft. of aggregate is required, so that the percentage of bitumen to aggregate is best expressed in percentages dependent on the weight of a cu. ft. of dry loose aggregate.

There is no definite relation between volume of unit weight of aggregate to dust below the No. 80 sieve.

The volume method is the most accurate method for the determination of the amount of bitumen required. The following table shows the analysis of five bituminous pavements having widely differing aggregates :—

Quality of Mixture	Sample No.	% Passing Mesh No												% of Agg.	% of Bit.	Sp G. of Agg.	% of Vds.
		1	¾	½	¼	⅛	10	20	30	40	50	80	100	200				
Waved	1	4 1	2		7 6	9 6	6 6	10 0	9 8	13 4	11 5	5 3	5 4	6 2	91 5	8·5	2 73	36·1
Good	2	9 2	14·5	27 1	11 2	2 5	3 9	5 1	7 6	4 7	3 2	1 0	3 2	94 1	5 9	2 82	46·7
,,	3			10 4	8	0·8	10 2	17 1	18 5	9 6	12 8	5 8	88 4	11 6	2 62	37·5
,,	4				1 6	1 6	8	4 3	4 3	4 4	65 0	82 0	18 0	2 90	59·3
Cracked	5				·4	5 3	14 6	16 5	20 0	17 8	7 5	5 0	2 7	40 8	9 2	2 30	43·2

An examination of these samples by summing up the percentage passing the 80, 100, 200 sieves will place Nos. 1 and 5 (inferior samples) between Nos. 2 and 3, and thus furnishes no clue to the causes of failure.

It is essential in all sheet asphalte work to obtain an absolutely even thickness (longitudinally) and a uniform surface, and this makes it necessary to employ only skilled men for this class of york. It will be observed that a slight excess of bitumen or a variation in the composition of the aggregate will produce an uneven wearing surface, due to a changing tractive resistance. Moreover, the bitumen will not behave uniformly under hot and

cold weather conditions, nor will the surface have a uniform resilience to traffic. This may result in waviness, cracking, or complete disintegration.

Sheet asphalte may be divided into three classes, the percentage of bitumen depending to a great extent upon climate and aggregate :—

1. Bituminous percentage less than 8 per cent.
2. Bituminous percentage between 8 and 10 per cent.
3. Bituminous percentage over 10 per cent.

With regard to the laying of sheet asphalte with a binder course it may be desirable and economical in cases to eliminate the latter and increase the thickness of the concrete base. This makes the repair of the wearing surface a more simple operation. If possible, a natural aggregate, such as sand or limestone, should

FIG. 62.—Section showing Reconstruction of Existing Macadam Road with Bituminous Binder Course and Sheet Asphalte Wearing Course.

be used rather than artificial graded aggregate, all of which are more costly.

The Author recently designed an asphalte pavement consisting of two binder courses, 2 and 1 in. in thickness respectively, laid on an old macadam bed and utilizing the screened excavated macadam for those courses, which were mixed with tar in a special tar-macadam plant. The base was tar sprayed, then the lower binder course laid and rolled, and a similar process for the upper binder course carried out : afterwards the sheet-asphalte wearing course was applied, as shown in Fig. 62.

Rock Asphalte.

Rock asphaltes, consisting of more or less pure limestone impregnated with bitumen, usually crush to a fine powder, each particle of which contains bitumen. It may contain bitumen up

to 15 per cent and it is capable of being compressed. When heated it forms a dense compact mixture, the particles of which are thoroughly cemented together by the bitumen.

The commercial product generally contains about 7 to 8 per cent of bitumen. Occasionally two or more grades of rock asphalte are blended in order to obtain the correct mixture for road work, otherwise the addition of petroleum or flux will secure the necessary consistency. The method of laying this rock asphalte is similar to that used for sheet asphalte. It is pulverized, heated, and mixed to the required temperature and then spread on the roughened concrete base or binder course. One of the chief objections to the rock asphalte pavement is the uncertainty of the percentage of bitumen in the batches of raw material. It is practically impossible to attempt to test the natural product to any extent, and the only safe method of obtaining a uniform mixture is by grinding it up thoroughly and mixing large quantities. Rock asphalte, therefore, has been partially superseded by the entirely artificial impregnation.

The process of laying sheet or rock asphalte may be simplified by heating and mixing the material at stationary plants and transporting it to the site. In this way the operation of the plant and the process of the grading and mixing is carried out under conditions which are conducive to efficiency and uniformity. As a hot powder, 300 to 350° F., it is laid by spreading with hot iron rakes to a uniform depth, and then rolled with a light roller or tamped with a 6-in. diam. tamper prior to rolling with an 8 to 10 ton roller.

The success of an asphalte pavement depends upon the point of complete compression by traffic not being reached and thus retaining its elastic or cushioning properties. When ultimate compression is attained the pavement begins to disintegrate.

Bituminous Concrete.

Bituminous concrete may be defined as a mixture composed of graded broken stone, clinker slag, or gravel with or without sand, or other inert material. The aggregate may be composed of one

product of the crushing or screening plant or a mixture of the product of such plant, with a proportion of sand or other similar material, with or without a filler. Where this class of pavement is to replace waterbound macadam, it is often practicable to use the material taken from the original road. If necessary this should be screened, washed, and dried. The coarse material should not exceed the 1½-in. mesh sieve, and preferably should be from 1 to 1¼ in. The correct proportion of bitumen for a particular grading is somewhat difficult to estimate. It may be as low as 5 per cent in the case of coarse mixtures, or as much as 10 per cent in the case of the finer mixtures. As with cement concrete and sheet asphalte, the densest possible mixture should be the objective of the engineer, and it is necessary to determine the relative proportion, or in other words the grading and void percentage, of the material. The practical engineer will be able to judge from an inspection and test of a sample of stone the approximate proportion of bitumen to be added.

The thickness of bituminous concrete—which should be laid in two courses—varies from 5 to 8 in.

The following table shows average gradings, etc., for typical bituminous concrete mixtures :—

		Mixtures.		
Average Grading of Bituminous Concrete.		1.	2.	3.
Passing 100-mesh sieve		6·3%	8·0%	8·8%
,, 80-mesh ,,		1·2%	1·0%	0·8%
,, 60-mesh ,,		2·5%	3·2%	3·2%
,, 40-mesh ,,		7·0%	6·1%	5·8%
,, 20-mesh ,,		8·0%	13·0%	12·3%
,, 10-mesh ,,		4·9%	10·2%	8·0%
,, 8-mesh ,,		1·3%	3·8%	2·8%
,, 4-mesh ,,		9·5%	17·0%	14·5%
,, ½-in. screen		26·3%	19·2%	25·2%
,, ¾-in. ,,		18·7%	13·7%	17·6%
,, 1-in. ,,		12·8%	5·0%	0·0%
,, 1¼-in. ,,		0·3%	6·0%	0·0%
Specific gravity of stone		2·93	2·97	2·86
,, ,, ,, sand		2·70	2·70	2·63
Percentage of voids in aggregate		21·98	20·76	21·39
Percentage bitumen soluble in CS₂		6·90	7·35	6·80

The Method of Mixing.

The mixing of bituminous concrete is generally carried out by means of a mechanical mixer. The plant required for this purpose, may consist of a stone drying and heating plant, separating sieves, melting kettle, portable hot mixer, and boiler or concrete mixer. The ordinary cement mixer may be used for mixing the material without heat during warm weather. The method of mixing this material is similar to that previously described for sheet asphalte. The hot material is then conveyed to the site and spread by means of hot shovels and iron rakes. It is then rolled by a light roller of 8 tons and finally rolled by a 10-ton roller ; the scaling of bitumen is then applied by means of a squeegee so that no surface voids are discernible. It is then covered by a thin layer of stone chippings, gravel, grit, or sand and, if necessary, further rolled. This covering layer may be applied by means of a distributor which may be hauled by the steam-roller. The sealing coat may be applied by means of a special apparatus attached to the roller.

Road Department Specification for Bituminous Concrete or Tar Macadam

The following is the Road Board specification for bituminous concrete pavement having a mineral aggregate composed of broken stone or slag :—

Foundation.

Same as in previous specification for pitch-grouted macadam.

Thickness of the Surface Coating.

The thickness of the surface coating, when consolidated by rolling, should be from 2 to 3 in. according to traffic requirements. For a greater thickness, the material should be applied in two coats. (Many of the uneven surfaces to-day are due to the rolling of too great a thickness of material in one operation.)

In the case of naturally hard subsoils, the total thickness of the road crust, including foundations, should not be less than 6 in., unless the subsoil is sufficiently hard in itself to act as a good foundation, in which case a thickness of 4 in. is allowable. For yielding subsoils a thickness of 11 in. should be provided.

Cross-section.

The finished surface should have a cross-fall of about 1 in 32 ; for further particulars see specification for pitch-grouted macadam.

The Aggregate.

The aggregate should be composed of broken stone or selected slag, and should contain at least 60 per cent broken to the size of 2 in., not more than 30 per cent of 1½ in., and 10 per cent of ¾ to ½ in. for closing. The last-mentioned should be kept separate and used as top dressing during rolling. The stone should be thoroughly dried before being coated with tar.

For making tar macadam, the tar should comply with the Road Department Specification Tar No. 2. The tar should be heated in a heater or " boiler " specially designed to prevent frothing, which will otherwise inevitably occur if the tar contains even a small percentage of water. The necessary temperature should be determined largely by the sensible heat of the stone treated with the tar and the mode of application and treatment. The desired temperature will be generally found in practice to be between 260° and 280° F., or 124° and 138° C., in the heater or boiler. The quantity of tar used to coat 1 ton of stone should be approximately from 9 to 12 gal., varying according to the size of the stone, the method used, and other conditions.

Laying and Rolling.

After being spread and levelled the material should be rolled into a smooth surface, but too much rolling should be avoided. Less rolling is required than in the case of waterbound macadam. A 10-ton roller is suitable in most cases, but good results can be obtained from using a 6-ton roller and finishing with a 10-ton roller.

Seal Coat.

After the road has been used for several weeks, a coating of tar should be applied to the surface. This tar should be sprayed or poured on the surface at a temperature of about 132° C. (270° F.). Stone chippings, crushed gravel, coarse sand, or other approved material, free from dust, not larger than will pass through a ¼-in. square mesh, should be used for gritting.

Clinker Asphalte.

The use of clinker aggregates for asphalte work, introduced by E. J. Lovegrove, Esq., M.Inst.C.E., Borough Engineer,

Hornsey, has been singularly successful in this country. The Author is enabled, through the courtesy of W. J. Hadfield, Esq., M.Inst.C.E., City Surveyor, Sheffield, to give herewith his specification for clinker asphalte paving.

Sheffield Specification for Clinker Asphalte Paving

The material used is hard-burnt destructor clinker, carefully selected.

This is crushed and screened, two sizes being used for the asphalte : $\frac{1}{2}$-in. mesh for the bottom coat and $\frac{1}{8}$-in. mesh down for the top coat.

The rejections are used for ordinary tar macadam.

The material is heated on sand dryers to a temperature of as nearly as possible 300° C.. it is then mixed (the two sizes separately) in a tar macadam mixing machine with revolving arms, steam-jacketed.

The proportion of bitumen should be about 10 per cent for the bottom coat and 17 per cent for the top coat. The bitumen mixture consists of 10 parts of mexphalte and 1 part of fluxphalte, also heated to 300° C.

The weight of the clinker is ascertained by filling it into gauge boxes before passing it into the mixer, and the weight of the bituminous mixture by measuring it in a bucket of known capacity.

When in the mixer the materials are mixed until the clinker is thoroughly coated with the bitumen. It is found sufficient if mixing goes on till one minute after the last bucketful of bitumen has been added.

It is essential that part of the clinker should be in the mixing machine before any of the bitumen is added.

While the mixed material is still quite hot it is put into a motor lorry and taken to the place where it is to be used.

The bottom coat is spread so as to have a depth, when rolled, of rather more than 1 in. and is then slightly rolled. The second coat is laid so as to have a thickness, when rolled, of rather less than 1 in., making a total thickness of 2 in. for the two layers.

As soon as a large enough area of the second coat is spread, further rolling commences and goes on until it is impossible to make any further impression on the material.

The surface is then dusted over with cement or limestone flour, and the traffic immediately allowed upon it.

The roller preferred is a 12-ton roller (lighter ones have been tried, but the heavier the roller the better the result).

In laying the material alongside tram rails no intermediate setts are used, but at the joint between the asphalte and the rail, the former is hammered down with a heavy hammer before the final passages of the steam-roller. Before the second coat is laid, the edges of the tram rails are painted with a mixture of mexphalte and fluxphalte.

One ton of material should cover about 12 super. yd.

The foundation may be of concrete, or a hard macadam road. Where setts are replaced, the space between the top of the old concrete and the under-side of the asphalte may be filled with old macadam, concrete, bricks, or other hard material well rolled down.

A typical grading of clinker used for this class of work is as follows :—

(a) Reject of $\frac{1}{8}$-in. screen : used for bottom coat :—

1. Passing $\frac{3}{8}''$ screen and retained on $\frac{5}{16}''$ screen			9·53%
2. ,, $\frac{5}{16}$,, ,, $\frac{1}{4}''$,,			9·69%
3. ,, $\frac{1}{4}''$,, ,, $\frac{3}{16}''$,,			28·44%
4. ,, $\frac{3}{16}''$,, ,, $\frac{1}{8}''$,,			26·87%
5. ,, $\frac{1}{8}''$ screen			25·47%
			100·00

(b) Passing $\frac{1}{8}$-in. screen : used for top or wearing coat :—

|		
Retained on 10 by 10 sieve	. . .	12·10%
Passed 10 by 10 sieve	. . .	22·50%
,, 20 ,, 20 ,, .	. . .	13·04%
,, 30 ,, 30 ,, .	. . .	4·84%
,, 40 ,, 40 ,, .	. . .	8·13%
,, 50 ,, 50 ,, .	. . .	3·75%
,, 76 ,, 76 ,, .	. . .	6·80%
,, 100 ,, 100 ,, .	. . .	11·40%
,, 200 ,, 200 ,, .	. . .	17·43%
		100·00

In general all bituminous roads should be protected or supported at the sides by a kerb or channel in order to take the thrust and to prevent the edges of the pavement from breaking away. If it is not desirable to lay a kerb above the surface of the road, it may be set level with the road surface. An interesting experiment has been carried out on a section of road in the East Riding of Yorkshire, near York, by J. W. Chapman, Esq., the County Surveyor. Bituminous concrete was reinforced to a depth of 4 to 5 in. with No. 9 B.R.C. fabric with excellent results. The surface of the road has remained in good condition, whereas the adjoining area of unreinforced road has worn very badly.

Maintenance.

All bituminous roads are comparatively easy to maintain and repair, as a definite section can be cut and re-surfaced. For patch repairs it is necessary to secure a sound abutment on all sides of the patch, and to obtain a completely sealed joint to this abutment. The Author suggests that some method of heating, by blow-lamps, for example, or special heating machines, to the edges of the undisturbed material will assist in welding the joint. Many of the repairs in sheet asphalte are carried out without this precaution being taken, and under winter conditions failure may result.

Rubber Roads.

There are many road users who consider rubber to be the ideal road material. There is very little data extant as to its wearing qualities or tractive resistance, but a report has recently been issued of a few experimental sections of road, notably in the Borough of Southwark. On one heavily trafficked road the surface was originally laid with rubber blocks attached to steel plates, but the method of attachment was afterwards improved. So far as can be ascertained at present the results are quite satisfactory. This type of road surface is noiseless, and causes no vibration. One objection which has been urged against rubber roads is that rubber tyres have a tendency to skid when running upon rubber : further experiments with this pavement will be observed by engineers and road users with great interest.
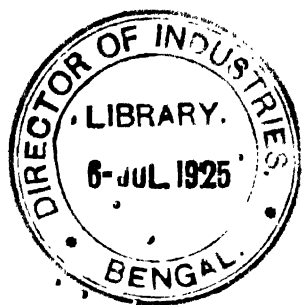
CHAPTER XI

CONCRETE ROADS

THE destructive effect of heavy mechanical traffic on the majority of existing roads in this country has brought about the construction of the paving surface itself in Portland cement concrete.

It will be shown elsewhere that surface inequalities of roads are due to the movement of the surface material itself, to a greater or lesser extent, and if no movement is possible, either horizontal or vertical, then wave formation is practically eliminated. In considering the advisability of adopting concrete for main roads, this point should be fully understood. The main difference between concrete and the other road formations lies in the binder, which, being of cement, forms in combination with the other constituents of concrete an absolutely rigid mass. This quality is absent from waterbound macadam, tar macadam, etc., none of which gives an absolutely unyielding surface nor is entirely resistant to deterioration.

One of the first concrete roads built in this country was laid at Saltney in the City of Chester, by Mr. Matthews-Jones, M.I.C.E., in 1912. From that time until recently the development of the concrete pavement has proceeded comparatively slowly. The time has now arrived when concrete as a road material is being taken more seriously, and a considerably increased mileage of this class of road is being laid down annually.

The points which should occur to the engineer in the selection of concrete as a paving material are as follows :—

1. Initial Cost.

The cost of laying a concrete slab is very little more than in laying a concrete foundation. *There is less excavation,* and in

many cases a strong existing foundation is available and may
permit a reduction in the thickness of the slab. 'The cost will
compare very favourably indeed with granite setts, wood blocks,
or bituminous paving when laid upon a concrete foundation.

It is not enough to compare merely the initial cost of a road ;
the cost of maintenance, its public utility, and wearing qualities
must also be considered.

2. Cleanliness.

The concrete road is a very sanitary pavement on account of
its smooth hard surface which practically is self-cleansing, and in
the absence of tar surface treatment the concrete does not
produce detritus or other material to be washed off in rainy
weather as is the case with some types of surface. This smooth-
ness also permits of a flatter camber or cross-fall only as shown
in Fig. 63, thus encouraging traffic to distribute itself more
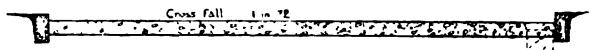
FIG. 63.—Concrete Slab with Side Fall only.

evenly over the whole road width and eliminating the general
tendency to wear down the crown and cause ruts for the lodg-
ment of water.

3. Noiselessness.

This point is an important one which must be examined and
compared, after two or three years' wear, with other smooth-
surfaced roads. In its initial stage it satisfies all requirements for
noiselessness.

4. Tractive Resistance.

Portland cement concrete has a low tractive resistance, a
property which makes it invaluable as a road material. This low
tractive resistance means a minimum vibration of traffic, also the
rear-axle vibration is practically eliminated, since this occurs
only when the surface is uneven ; for instance, a joint $\frac{1}{2}$ to 1 in.
wide would set up a slight vibration which would have literally
no destructive effect on the concrete.

5. Economy of Maintenance.

Assuming that the concrete road is properly constructed, the cost of maintenance of this type of surface depends upon several factors as follows :—

(a) Nature and volume of traffic.

(b) Width of road.

(c) Foundation and subsoil.

(d) Drainage.

(e) Necessity for or omission of reinforcement.

(f) Necessity for application of tar or bituminous dressing to the surface for the joints.

Up to the present American and British experience indicates that the cost of maintenance of concrete road surfaces is very low. This cost will decrease with the decline of horse traffic and the increase of solid and pneumatic rubber tyres.

• The disadvantages of concrete as a road surface which present themselves at the moment are as follows :—

1. Reinstatement.

The difficulty of reinstatement after any disturbance of the road has taken place has already been alluded to ; in this respect, however, it should be remembered that the extended use of concrete upon roads will compel mains authorities to avoid, as far as possible, the disturbance of such roads on account of the greater expenditure incurred in the process.

2. Gradients.

On steep gradients concrete will be ruled out as impracticable —its smooth surface affording an insufficient grip for horse traffic. It should be noted, however, that the application of tar, or bitumen and chippings, increases the tractive resistance and temporarily supplies this deficiency. Having regard to the rapid decrease of horse traffic on main roads, this objection should not be taken too seriously. For the time being, the up-side of the road may be laid quite easily with concrete, together with a longitudinal strip of non-slip granite setts about 3 ft. wide laid in the centre flush with the concrete.

3. Difficulties of Construction.

There are several difficulties to be encountered in constructing
a road in concrete, but it is possible for the experienced engineer
to circumvent them with results so satisfactory that the dis-
advantages amount to very little. It is sometimes inconvenient
to close a road entirely to traffic during construction ; in this case
half the width of the surface can be dealt with at a time. Although
this method does not necessarily hinder the success of the road,
it should be avoided on the ground of economy. Another diffi-
culty is the possibility of frosty weather interfering with the
setting of the cement and holding up the work for varying
periods ; obviously, therefore, concrete road construction should
be avoided during a cold spell.

Treatment of Foundations.

The success of the concrete road is not a little due to proper
treatment of the subgrade and foundation of the road. Where
the subsoil is waterlogged, drains and cross trenches should be
laid to pass away the water which would otherwise remain under
the slab. Where the natural drainage conditions and the subsoil
are good no special provision need be made.

Generally speaking, a new foundation bed is improved in its
bearing qualities by a layer of 2 or 3 in. of cinders, gravel, sand,
or broken stone, which, incidentally, will assist in keeping the
top surface of the subsoil drained. Where concrete is being
substituted for existing road material the matter of foundation
is comparatively simple, although it may still be necessary to
provide subsoil drainage where soft ground is suspected.

Foundation for Filled-in Ground.

Occasionally it happens that a road is carried upon an embank-
ment built of filled-in earth or similar material, and in such cases
the greatest possible care must be exercised to obtain a uniformly
consolidated base. There are many ways in which this can be
effected in actual practice, such as by rolling, watering, and
running traffic before finishing the road.

The embankment should be constructed of suitable earth in

successive layers from slope to slope. Each layer should not exceed 1 ft. in depth and should be rolled by a roller weighing from 5 to 10 tons. To assist drainage the sides of the embankment should be kept slightly lower than the centre, at all stages of construction, and the earth should be continually wetted to ensure consolidation : it should be observed, however, that greater solidity is obtained by sloping the layers inwards to the centre.

The selection of a type of paving suitable for such a road surface will depend on local conditions and costs ; the concrete road, however, is quite suitable for the embankment if the slab is reinforced. This distributes the weight from the traffic evenly over the surface of the embankment, and any general or local settlement which takes place is less likely to cause cracking.

Materials.

The whole secret of success of the concrete road centres round the care bestowed upon the selection, proportioning, mixing, and laying of the various materials. The principal aim in arranging suitable mixtures of concrete should be to obtain the maximum density, as this only will give maximum strength.

Cement.

The following is an abstract of the requirements of the British Standard Specification for Portland cement (1920).

Fineness.

Residue on a sieve having 32,400 meshes per sq. in. (diam. of wire ·002 in.) not to exceed 14 per cent.

Residue on a sieve having 5,776 meshes per sq. in. (diam. of wire ·0044 in.) not to exceed 1 per cent.

Tensile Strength.

Briquettes to be of 1 sq. in. cross-section ; strain to be applied at the rate of 100 lb. in 12 seconds.

Neat Cement.

After 7 days, breaking stress to be not less than 450 lb.

Increase from 7 to 28 days to be not less than the number of

pounds per square inch of section arrived at from the following formula :—

$$\text{Breaking strength at 7 days} + \frac{40{,}000 \text{ lbs.}}{\text{Breaking strength at 7 days.}}$$

Cement and Sand.

1 part of cement to 3 parts by weight of standard sand.

After 7 days breaking stress to be not less than 200 lb.

Increase from 7 days to 28 days to be not less than the number of pounds per square inch of section arrived at from the following formula :—

$$\text{Breaking strength at 7 days} + \frac{10{,}000 \text{ lb.}}{\text{Breaking strength at 7 days.}}$$

Setting Time.

To be determined by the Vicat Needle Apparatus :—

QUICK.—Initial Set not less than 2 min.
        Final Set ,,   ., 10 min. nor more than 30 min.
SLOW.—Initial Set .,   ., 30 min.
        Final Set ..   ., 3 hrs., nor more than 7 hrs.

Soundness.

Le Chatelier Expansion to be not more than 10 mm. after 24 hours' aeration. or if this fails, 5 mm after 7 days' aeration.

$$\text{Ratio} \frac{\text{Lime}}{\text{Silica} + \text{Alumina}} \quad \frac{\text{Chemical Composition}}{\text{(in chemical equivalents)}} = \frac{\text{from } 2\cdot00}{\text{to } 2\cdot85}$$

Insoluble residue not to exceed 1·5 per cent, magnesia 3 per cent, sulphuric anhydride 2·75 per cent. Loss on ignition not to exceed 3 per cent.

Note.—Cement to be aerated for a period of 24 hrs. before tests for tensile strength or soundness are carried out.

Delivery.

Cement shall be delivered in packages bearing the manufacturer's name.

Aggregate.

The aggregate may be divided into two sections, i.e. coarse and fine. As with all tarred and bituminous roads the function of the fine aggregate is to fill the voids made by the coarse aggregate in order that the finished concrete will not be in any way unequal.

Fine Aggregate.

This should consist of sandstone, slag, granite, or other stone screening from ¼ in. down to dust. It should be fine, clean, hard, and durable. It is usual to specify that the sand should be sharp, but round particles are equally, if not more, suitable for dense mixtures.

In view of the great importance attaching to the grading of the material for the purposes of denseness it is advisable to make sieve analyses of the material from time to time as it is being used. As previously shown, the sieves usually employed for fine aggregates in British practice are as follows :—

10 by 10 per sq. in.	50 by 50 per sq. in.
20 ,, 20 ,, ,,	80 ,, 80 ,, ,,
30 ,, 30 ,, ,,	100 ,, 100 ,, ,,
40 ,, 40 ,, ,,	200 ,, 200 ,, ,,

The analysis conducted with these sieves will indicate the value of sand for mortar and concrete work. The surface area of the sand particles varies with the degree of coarseness, and this determines the quantity of cement required. The sand should be sampled with representative quantities for the sieve tests and also for determination of voids in the fine material. The necessity of washing the aggregate is proved by shaking the sample in a flask or cylinder half full of water. The appearance in colour and the amount of suspended solids will indicate at once the need for washing. This is only a rough test, but it is one that can be readily applied on the site of the proposed works.

Organic impurities in sand may be determined by shaking a few ounces of the sand in a 3 per cent solution of sodium hydroxide and noting the appearance upon the settlement of the liquor overnight. If it is colourless or light yellow no organic impurities are present ; on the other hand, a brown colour shows that the sand is unsuitable for road work. Washing is generally sufficient to remove most of the impurities usually found in sand deposits.

Another test for checking the proportions of the materials is to mix the two aggregates and cement in suitable proportions

with water to attain the same consistency as used on the works, when further examination of the proportions of the aggregate and cement may be made in several ways. One method is to place a fresh sample of concrete in a cylinder of water and shake until the whole of the materials are in suspension; on allowing to settle, the coarse aggregate will fall to the bottom first, the sand next, and finally the cement. The depth of the various materials in the cylinder will be a good guide as to the accuracy used in mixing.

Determination of Voids in Sand or Coarse Material.

This test is carried out by measuring the quantity of sand or coarse aggregate in one cylinder well tamped and shaken with sufficient water to cover the material, so that the result will not be inaccurate by reason of water absorbed by the dry material itself. A sufficient quantity of water is then measured in a second cylinder and the aggregate poured slowly from the first cylinder into it. The percentage of voids is then found by noting the level of the aggregate in the measuring cylinder, adding the amount of water taken and subtracting the reading shown at the top of the water. The difference between the amount of water taken on the reading shown at the top of the water will give the amount of voids in volume of the material.

Proportioning by Voids.

The methods of proportioning by voids are based upon the requirement that the voids of the coarse aggregate will be filled up by the fine aggregate with a little excess, while the cement will fill the voids of the fine aggregate also with a little excess. The surplus allowed in each case is necessary, because the voids of the two aggregates are increased by the insertion of the respective finer materials. Having determined the voids in sand and coarse material, the concrete should be proportioned so that the sand is sufficient to fill the voids of the larger material with an excess of 10 per cent and the cement paste about 10 to 15 per cent in excess of the voids in the sand. By this means the proportions can be regulated to give the densest practicable mixture of concrete. One of the difficulties in attaining a high degree of

accuracy by this method is that of obtaining a correct and representative value in practice for the voids.

As an illustration of this method let it be assumed that the coarse aggregate has 45 per cent voids and the fine aggregate 40 per cent voids.

Take 1 part or 1 cu. ft. of stone :

Then 0·55 = vol. of stone.

$\qquad$ 0·45 = voids.

Now fine aggregate must equal 0·45

$\qquad$ plus 10% = 0·495.

The voids in the fine aggregate are 40 per cent of 0·495 = 0·198. Now cement paste should equal, say, 15 per cent above the voidage in the fine aggregate = 0·198 × 1·15 = 0·228. But 1 cu. ft. of cement powder makes approximately 0·85 cu. ft. of cement paste,

$\therefore \quad \dfrac{0·228}{0·85} = 0·268$ cu. ft. cement.

The proportions then are :—

	cu. ft.
Coarse aggregate	1·0.
Fine ..	0·495.
Cement . .	0·268.

Taking cement as one part these quantities give a proportion of 3·74 : 1·85 : 1.

Proportion of Water to Concrete and its Strength.

One of the most vital points in carrying out concrete road work is that of maintaining the right proportion of water in mixing the concrete. It is a common practice to leave this to guess-work, and the natural tendency is to make the concrete too wet or sloppy. A curious fact is that the correct amount of water cannot be determined by the appearance of the mixture, and it is absolutely essential that the proportion of water should be adhered to independently of its condition. An excess of water of 10 to 15 per cent actually causes a decrease in strength of nearly 50 per cent, hence the necessity of proportioning the water scientifically.

Professor Abrams has conducted an exhaustive research into this branch of concrete work and has evolved a basis for proportioning water to concrete as a result of approximately 50,000 tests. He states that : " our experimental work has emphasized the importance of water in a concrete mixture, and has shown that the water is in effect the most important ingredient, since very small variations in the water content produce more important variations in the strength and other properties of concrete than similar changes in the other ingredients." (Design of Concrete Mixtures Bulletin, No. 1, by D. A. Abrams, Professor, Lewis Institute, Chicago.)
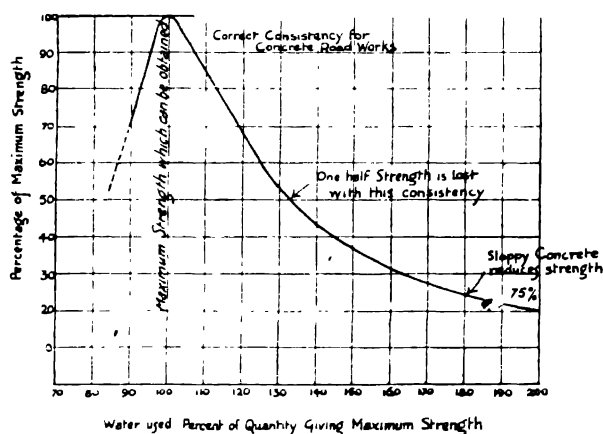

Fig. 64.—Graph showing Strength of Concrete compared with Percentage of Water used.

Fig. 64 shows the percentage of maximum curve in the strength compared with the percentage of quantity of water used that will give maximum strength.

Vertical distances show the relative strength of the concrete with varying percentage of water as a percentage of the maximum which can be obtained from the same mixtures of cement and aggregate.

Horizontal distances show the relative quantity of water used in the mixture, considering the amount which gives the maximum strength as 100 per cent.

Professor Abrams states, however, that the quantity required. is governed by :—

(1) the condition of " workability " of the concrete which must be used.
(2) the normal consistency of the cement ;
(3) the size and grading of the aggregate measured by the fineness modulus.

He also gives the following equation for comparative strength of concrete and water content :—

$$S = \frac{A}{B(x)} \quad \cdots \cdots \cdots (1)$$

Where S is the strength of the concrete and x the ratio of volume of water to the volume of cement in the mixture : A and B are constants.
The values of each depend upon the quality of cement used, the age of the concrete and the curing conditions, etc.
For the conditions under which Professor Abrams' tests were made his formula becomes :—

$$S = \frac{14,000}{.7(x)} \quad \cdots \cdots (2)$$

The curve in Fig. 64 is an average of the results of tests of the several mixtures. He then finds the following relations between the quantity of water for giving proportions and conditions :—

$$x = R \left[\frac{3}{2}p + \left(\frac{0.30}{1.26m} + a - c \right) n \right] \quad \cdots (3)$$

or approximately :—

$$x = R \left[\frac{3}{2}p + \left(\frac{m}{12} + a - c \right) n \right] \quad \cdots (4)$$

Where x represents the water ratio

$$\frac{\text{Volume of Water}}{\text{Volume of Cement}},$$

R the relative consistency of concrete or " workability factor."
Normal consistency, p, requires the use of such a quantity of mixing water as will cause a slump or settlement of $\frac{1}{2}$ to 1 in. in a freshly moulded 12 × 6 in. diameter cylinder of about 1 : 4 mixture upon withdrawing the form by a steady upward pull The relative consistency of 1·10 requires the use of 10 per cent more water,

and under the above conditions will give a slump of about 5 to 6 in.

p = the ratio by weight of water to mixture (see above).

m = the fineness modulus of aggregate.

a = absorption of aggregate 'three hours' immersion.

c = the moisture contained in aggregate—ratio volume content of volume of aggregate.

The Fineness Modulus.

The " Fineness Modulus " is determined by making a sieve analysis, using Tyler's standard sieves in which a clear mesh opening in each sieve is just double that of the preceding one.

A sieve analysis is expressed in terms of either volume or weight as the percentage coarser than each sieve.

The fineness modulus of the aggregate is defined as the sum of the percentage given by the sieve analysis divided by 100.

TABLE 1

FINENESS MODULUS

Sieve Size.	Size of Square Opening		Sieve Analysis of Aggregates. Per cent of sample coarser than a given sieve.						Concrete Aggregate G.[1]
			Sand.			Pebbles.			
	in.	mm	Fine A	Medium B.	Coarse C.	Fine D	Medium E.	Coarse F.	
100 mesh	·0058	·147	82	91	97	100	100	100	98
48 mesh	·0116	·295	52	70	81	100	100	100	92
28 mesh	·0232	·59	20	46	63	100	100	100	86
14 mesh	·046	1·17	0	2	44	100	100	100	81
8 mesh	·093	2·36	0	10	25	100	100	100	78
4 mesh	·185	4·70	0	0	0	86	95	100	71
⅜ inch	·37	9·4	0	0	0	51	66	86	49
¾ inch	·75	18·8	0	0	0	9	25	50	19
1½ inch	1·5	38·1	0	0	0	0	0	0	0
Fineness modulus			1·54	2·41	3·10	6·46	6·86	7·36	5·74

[1] Concrete aggregate G is made up of 25 per cent of sand " B " mixed with 75 per cent of pebbles " E " Equivalent gradings would be secured by mixing 33 per cent sand " B " with 67 per cent coarse pebbles " F "; 28 per cent " A " with 72 per cent " F," etc The proportion coarser than a given sieve is made up by the addition of these percentages of the corresponding size of the constituent materials

In actual practice it is almost impossible to attain complete accuracy ; it is, therefore, essential to know the amount of variation permissible for the fineness modulus of aggregates. Prof. Abrams' table is given below :—

TABLE II

MAXIMUM PERMISSIBLE VALUES OF FINENESS MODULUS OF AGGREGATE

Proportion of Cement to Aggregate.	Meshes per inch.													
	0—28	0—14	0—8	0—4	0—3	0—:"	0—½"	0—¾"	0—1"	0—1½'	0·2·1"	0—3"	0—4½"	0—6"
1–12	1·20	1·80	2 40	2 95	3·35	3·80	4·20	4·60	5·00	5 35	5·75	6·20	6 60	7·00
1–9	1 30	1·85	2·45	3·05	3 45	3 85	4 25	4 65	5·00	5 40	5·80	6 25	6·65	7·05
1–7	1·40	1 95	2 55	3·20	3 55	3 95	4 35	4·75	5·12	5 55	5·95	6·40	6·80	7·20
1–6	1 50	2 05	2 65	3 30	3·65	4 05	4 45	4·85	5 25	5·65	6·05	6·50	6·90	7·30
1–5	1 60	2 15	2·75	3 45	3 80	4·20	4 60	5·00	5·40	5 80	6 20	6 60	7·00	7·45
1–4	1·70	2 30	2 90	3 60	4 00	4 40	4·80	5 20	5·60	6·00	6 40	6 85	7·25	7·65
1–3	1·85	2·50	3 10	3 90	4 30	4·70	5 10	5·50	5 90	6 30	6 70	7·15	7·55	8·00
1–2	2·00	2·70	3 40	4·20	4·60	5 05	5 45	5 90	6 30	6 70	7·10	7 55	7 95	8·40
1–1	2 25	3 00	3·80	4 75	5 25	5 60	6 05	6·50	6 90	7 35	7 75	8·20	8·65	9·10

Size of Aggregate for Concrete.[1]
Limits of Grading.

[1] Considered as " half-size " sieves ; not used in computing fineness modulus.

For maximum sizes of aggregate and for mixtures other than those given in the table, use the next smaller size and the next leaner mix respectively. For other classes of aggregate reduce values as follows :—

TABLE III

REDUCING VALUES

Crushed stone or slag .	0·25
Crushed material unusually flat or elongated . .	0·40
Pebbles consisting of flat particles . .	0·25
Stone screenings (if machine mixed omit reduction) .	0·25

It is not advisable to use sand with a lower fineness modulus than 1·50 in ordinary concrete mixtures.

Crushed stone mixed with both finer sand and coarser pebbles requires no reduction in fineness modulus, provided the quantity of crushed stone is less than 30 per cent of the total volume of the aggregate.

TABLE IV

Professor Abrams' Table of Proportions and Quantities for One Cubic Yard of Concrete

Based upon laboratory investigations using approved materials. Compressive strength, twenty-eight days with workable plasticity, 6 by 12-inch cylinders, 3000 pounds per square inch.

Size. Coarse aggregate Inches.	Cement in barrels Aggregates in cubic yards	Fine aggregate screen openings per inch.														
		0–28			0–14			0–8			0–4			0–¾ in.		
	Proportions / Quantities	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse
No. 4 screen to ¾	P.	1	1.3	2.4	1	1.6	2.4	1	1.8	2.3	1	2.0	2.3	1	2.7	1.5
	Q.	1.96	.37	.69	.95	.44	.66	.82	.48	.62	.75	.52	.59	1.79	.72	.40
No. 4 screen to 1	P.	1	1.3	2.7	1	1.6	2.6	1	1.8	2.6	1	2.0	2.5	1	2.6	1.8
	Q.	1.90	.36	.76	.77	.42	.68	.72	.46	.66	.67	.50	.62	1.72	.66	.46
No. 4 screen to 1½	P.	1	1.2	3.1	1	1.6	3.2	1	1.7	3.1	1	2.0	3.0	1	2.4	2.4
	Q.	1.82	.32	.84	.68	.40	.79	.63	.41	.75	.61	.47	.72	1.62	.57	.51
No. 4 screen to 2	P.	1	1.2	3.3	1	1.5	3.5	1	1.6	3.7	1	1.9	3.6	1	2.2	3.1
	Q.	1.75	.31	.90	.63	.36	.85	.55	.36	.85	.52	.43	.81	1.53	.50	.70
No. 4 screen to 2½	P.	1	1.2	3.8	1	1.4	3.9	1	1.6	4.0	1	1.8	4.0	1	2.1	3.5
	Q.	1.72	.28	.97	.58	.33	.91	.51	.35	.89	.49	.40	.88	1.60	.46	.78
No. 4 screen to 3	P.	1	1.2	3.9	1	1.4	4.1	1	1.5	4.1	1	1.7	4.1	1	2.0	3.7
	Q.	1.60	.28	.97	.58	.33	.97	.49	.33	.90	.49	.37	.90	1.49	.44	.81
No. ¾ screen to ¾	P.	1	1.3	2.3	1	1.7	2.3	1	1.9	2.3	1	2.2	2.2	1	2.8	1.4
	Q.	1.96	.37	.67	.77	.46	.63	.82	.51	.62	.75	.57	.57	1.79	.75	.37
No. ¾ screen to 1	P.	1	1.3	2.6	1	1.7	2.6	1	1.9	2.5	1	2.2	2.4	1	2.7	1.7
	Q.	1.90	.36	.74	.77	.44	.68	.72	.48	.64	.67	.54	.59	1.72	.68	.43
No. ¾ screen to 1½	P.	1	1.3	3.0	1	1.7	3.0	1	1.9	3.0	1	2.1	2.9	1	2.6	2.2
	Q.	1.82	.36	.80	.58	.43	.75	.63	.46	.73	.61	.50	.68	1.62	.63	.53
No. ⅜ screen to 2	P.	1	1.3	3.3	1	1.7	3.4	1	1.8	3.5	1	2.0	3.4	1	2.4	2.9
	Q.	1.75	.34	.86	.63	.41	.83	.55	.42	.80	.52	.45	.77	1.53	.62	.66
No. ⅜ screen to 2½	P.	1	1.3	3.7	1	1.6	3.7	1	1.7	3.9	1	2.0	3.8	1	2.3	3.3
	Q.	1.72	.33	.95	.58	.37	.87	.51	.37	.87	.49	.44	.84	1.50	.51	.74
No. ⅜ screen to 3	P.	1	1.3	3.8	1	1.6	3.9	1	1.7	4.0	1	1.9	4.0	1	2.2	3.5
	Q.	1.60	.33	.95	.62	.37	.01	1.49	.47	.48	1.49	.42	N	1.49	.48	.77

		1·96	1·5 ·44	1 ·85	2·3 ·67	1·9 ·52	1 ·85	1 ·82	2·2 ·61	1 ·82	2·1 ·56	2·2 ·59	1 ·75	2·3 ·59	2·1 ·54	1 ·79	2·8 ·75	1·3 ·34
No. ½ screen to ½	P. Q.	1 ·90	1·5 ·42	1 ·77	2·5 ·70	1·9 ·50	1 ·77	1 ·72	2·5 ·66	1 ·72	2·1 ·53	2·4 ·61	1 ·67	2·3 ·57	2·4 ·50	1 ·72	2·8 ·72	1·6 ·41
No. ½ screen to 1	P. Q.	1 ·82	1·4 ·37	1 ·66	2·8 ·75	1·9 ·47	1 ·66	1 ·63	2·9 ·73	1 ·63	2·1 ·51	2·9 ·69	1 ·61	2·2 ·52	2·8 ·66	1 ·62	2·7 ·65	2·1 ·51
No. ½ screen to 1½	P. Q.	1 ·75	1·4 ·36	1 ·63	3·3 ·86	1·9 ·46	1 ·63	1 ·55	3·3 ·79	1 ·55	2·0 ·46	3·4 ·78	1 ·52	2·3 ·50	3·3 ·74	1 ·53	2·7 ·62	2·7 ·62
No. ½ screen to 2	P. Q.	1 ·72	1·4 ·35	1 ·58	3·6 ·91	1·8 ·43	1 ·58	1 ·51	3·6 ·85	1 ·51	1·9 ·42	3·7 ·83	1 ·49	2·1 ·46	3·7 ·81	1 ·50	2·6 ·59	3·1 ·69
No. ½ screen to 2½	P Q	1 ·68	1·3 ·33	1 ·58	3·7 ·92	1·8 ·42	1 ·58	1 ·49	3·8 ·89	1 ·49	1·8 ·40	3·9 ·96	1 ·49	2·1 ·46	4·0 ·88	1 ·49	2·4 ·53	3·3 ·63
No. ½ screen to 3	P Q	1 ·90	1·5 ·48	1 ·77	2·4 ·68	2·1 ·55	1 ·77	1 ·72	2·4 ·62	1 ·72	2·4 ·61	2·1 ·53	1 ·67	2·6 ·64	2·2 ·55	1 ·72	3·1 ·79	1·5 ·39
No. ¾ screen to 1½	P Q	1 ·92	1·7 ·46	1 ·79	2·7 ·73	2·0 ·50	1 ·79	1 ·65	2·8 ·70	1 ·65	2·3 ·55	2·7 ·65	1 ·61	2·5 ·59	2·7 ·64	1 ·56	3·0 ·73	2·0 ·48
No. ¾ screen to 2	P Q	1 ·75	1·7 ·44	1 ·63	3·1 ·80	2·0 ·48	1 ·63	1 ·55	3·1 ·75	1 ·55	1·8 ·53	3·1 ·72	1 ·52	2·5 ·54	3·0 ·67	1 ·56	3·0 ·68	2·4 ·55
No. ¾ screen to 2½	P Q	1 ·72	1·7 ·43	1 ·58	3·3 ·94	2·0 ·47	1 ·63	1 ·51	3·5 ·83	1 ·51	1·9 ·52	3·4 ·76	1 ·49	2·4 ·53	3·4 ·73	1 ·50	2·9 ·64	2·8 ·62
No. 1 screen to 3	P Q	1 ·68	1·7 ·43	1 ·58	3·5 ·88	2·0 ·47	1 ·58	1 ·49	3·7 ·87	1 ·49	1·9 ·51	3·7 ·81	1 ·49	2·6 ·62	3·6 ·79	1 ·50	2·8 ·62	3·1 ·68
No. 1 screen to 1½	P. Q.	1 ·92	1·7 ·46	1 ·63	3·2 ·83	2·0 ·50	1 ·63	1 ·63	2·9 ·73	1 ·63	1·3 ·55	3·3 ·76	1 ·61	2·6 ·62	3·3 ·74	1 ·62	3·1 ·75	2·0 ·48
No. 1 screen to 2	P Q	1 ·75	1·5 ·39	1 ·58	3·4 ·86	1·9 ·46	1 ·63	1 ·58	3·5 ·85	1 ·58	2·2 ·51	3·3 ·76	1 ·52	2·4 ·54	3·3 ·74	1 ·53	3·0 ·68	2·6 ·59
No. 1 screen to 2½	P. Q.	1·72	1·4 ·35	1 ·58	3·4 ·86	1·9 ·45	1 ·58	1 ·51	3·8 ·80	1 ·51	2·0 ·44	3·7 ·83	1 ·49	2·3 ·51	3·7 ·81	1 ·50	2·7 ·59	3·1 ·69
No. 1 screen to 3	P. Q.	1·67	1·3 ·33	1 ·58	3·6 ·90	1·8 ·42	1 ·58	1·49	4·0 ·94	1·49	2·0 ·44	3·9 ·86	1 ·49	2·2 ·48	3·9 ·86	1·49	2·7 ·59	3·3 ·73

P.=Proportions of coarse and fine aggregates to cement.
Q.=Volume in cu. yds. coarse and fine aggregates to number of barrels of cement.
Note.—One barrel of cement=4 cub. feet.

The following example illustrates the application of Professor Abrams' investigations in the design of concrete mixtures :—

Take the following aggregates :—

				Coarse Aggregate.	Fine Aggregate.
100 mesh	.	.	.	100	82
48	.	.	.	100	52
28	.	.	.	100	20
14	.	.	.	100	0
8	.	.	.	100	0
4	.	.	.	95	0
$\frac{3}{8}$ in.	.	.	.	66	0
$\frac{3}{4}$ in.	.	.	.	25	0
$1\frac{1}{2}$ in.	.	.	.	0	0
Fineness modulus	.	.	.	6·86	1·54

Since more than 20 per cent is coarser than the $\frac{3}{8}$ in. sieve, the maximum size of aggregate is $\frac{3}{4}$ in.

From Table II the maximum value of fineness modulus which may be used for, say, a 5 : 1 mixture is 5·00. Thus by taking 65 per cent of coarse aggregate and 35 per cent of fine aggregate we obtain the necessary fineness modulus.

If $P = 100 \dfrac{A - B}{A - C}$, where

P is the percentage of fine aggregate in the total mixture,
A the fineness modulus of the coarse aggregate,
B   ,,   ,,   ..   final aggregate mixture,
C   ..   ..   ..   fine aggregate.

$$P = 100 \frac{6·86 - 5·00}{6·86 - 1·54} = \frac{186}{5·32} = 35\%.$$

By reference now to Table V the quantity of water may be found for the given mixture and a suitable consistency—say, 1·10.

The values obtained on the work will depend on such factors as the consistency of the concrete, quality of the cement, method of mixing, handling, placing the concrete, etc., and on the age and curing conditions.

Strength values higher than given for relative consistency of 1·10 should seldom be considered in designing, since it is only in exceptional cases that a consistency drier than this can be

satisfactorily placed. For wetter concrete much lower strengths must be considered.

Table IV (pages 142, 143) enables the necessary quantities and proportions of aggregate and matrix to be calculated for standard conditions.

This table shows the various proportions by which to combine a variety of fine aggregates of five selected sizes, with various sizes of coarse aggregates. The fine aggregates, or sands, shown in the table, include, first, one with all particles passing a sieve with 28 openings per linear inch, and another with 14 openings, one with 8, one with 4, and a sand with ⅜-in. size particles down. The range of coarse aggregate is apparent from the table.

To determine whether a given aggregate is to be classed as 3 in. or 2½ in. or 2 in., or whatever the upper limit of size may be, there should be not less than 10 per cent of the sample between the 3-in. and 2½-in. sizes ; otherwise it will be classed as 2½-in. size. Similarly, if there are 2-in. pieces it will be classed as 2-in. aggregate if there is not less than 10 per cent between 1½-in. and 2-in. sizes.

For fine aggregates there should be of the coarser material not less than 15 per cent between the coarser size and the next smaller screen opening. Thus, if a fine aggregate is to be classed as ¼-in. size, there should be not less than 15 per cent between the ⅛-in. screen and the ¼-in. screen.

With the ¼-in. sand down, the one usually specified, and with the coarse aggregate varying from that held on a No. 4 sieve to that passing a 1½-in. opening, the usual proportions of 1 : 2 : 3 were taken, and, with a workable plasticity or practical consistency, such a mixture produces a concrete with a crushing strength at 28 days of 3000 lb. per sq. in. in the form of 6 × 12-in. cylinders. All the other proportions and combinations are computed to give the same strength concrete as the 1 : 2 : 3 mixture.

The following table enables the necessary quantity of water to be calculated for average conditions.

Table IV has been determined from laboratory measurements and is compiled for concrete required for road work ; allowance therefore should be made for waste in the aggregate in handling the work, and another table calculated with this table as a basis, when concrete of different quality and strength is required.

The consistency of concrete for maximum strength may be determined by Mr. F. N. Romans' " slump " test. The apparatus used for this test consists of a metal truncated cone 12 in. high,

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having a base 8 in. and a top 4 in. (Fig. 65). This cone is filled with freshly mixed concrete and struck with a trowel. On carefully raising and drawing the mould, the fall of the struck surface is measured 1 min. after withdrawal of the cone. For concrete

TABLE V

QUANTITY OF MIXING WATER REQUIRED FOR CONCRETE

Gallons of water per sack (1 cu. ft.) of cement, using aggregates of different fineness modulus

Misc. cement. Agg. coy. vol.	1·50	2·00	2·50	3·00	3·50	4·00	4·50	5·00	5·50	6·00	6·50	7·00	
RELATIVE CONSISTENCY—(R) = 1·00													
1–12	23·5	21·4	19·5	17·8	16·4	15·2	13·9	12·9	12·0	11·1	10·4	9·8	gal.
1–9	18·1	16·7	15·2	14·0	12·9	12·0	11·0	10·2	9·6	9·0	8·4	7·9	,,
1–7	14·7	13·5	12·3	11·4	10·6	9·9	9·1	8·6	8·0	7·6	7·2	6·7	,,
1–6	13·0	12·0	11·0	10·2	9·5	8·9	8·3	7·7	7·3	6·8	6·5	6·2	,,
1–5	11·2	10·4	9·5	8·9	8·3	7·8	7·3	6·9	6·4	6·1	5·8	5·5	,,
1–4	9·5	8·9	8·2	7·7	7·2	6·8	6·3	6·0	5·7	5·4	5·2	5·0	,,
1–3	7·8	7·2	6·7	6·3	6·0	5·7	5·4	5·1	4·9	4·6	4·5	4·3	,,
1–2	6·0	5·7	5·4	5·1	4·9	4·7	4·5	4·3	4·1	4·0	3·9	3·8	,,
1–1	4·3	4·1	3·9	3·8	3·7	3·6	3·5	3·4	3·3	3·2	3·2	3·1	,,
RELATIVE CONSISTENCY—(R) = 1·10													
1–12	25·8	23·6	21·4	19·6	18·1	16·7	15·3	14·2	13·2	12·2	11·4	10·8	gal.
1–9	19·9	18·4	16·7	15·4	14·2	13·2	12·1	11·2	10·6	9·9	9·2	8·7	,,
1–7	16·2	14·9	13·5	12·5	11·7	10·9	10·0	9·5	8·8	8·4	7·9	7·4	,,
1–6	14·3	13·2	12·1	11·2	10·5	9·8	9·1	8·5	8·0	7·5	7·2	6·8	,,
1–5	12·3	11·4	10·5	9·8	9·1	8·6	8·0	7·6	7·0	6·7	6·4	6·1	,,
1–4	10·5	9·8	9·0	8·5	7·9	7·5	6·9	6·6	6·3	5·9	5·7	5·5	,,
1–3	8·6	7·9	7·4	6·9	6·6	6·3	5·9	5·6	5·4	5·1	5·0	4·7	,,
1–2	6·6	6·3	5·9	5·6	5·4	5·2	5·0	4·7	4·5	4·4	4·3	4·2	,,
1–1	4·7	4·5	4·3	4·2	4·1	4·0	3·9	3·7	3·6	3·5	3·5	3·4	,,
RELATIVE CONSISTENCY—(R) = 1·25													
1–12	29·4	26·8	24·4	22·2	20·5	19·0	17·4	16·1	15·0	13·9	13·0	12·3	gal.
1–9	22·6	20·9	19·0	17·5	16·1	15·0	13·8	12·7	12·0	11·2	10·5	9·9	,,
1–7	18·4	16·9	15·4	14·3	13·2	12·4	11·4	10·7	10·0	9·5	9·0	8·4	,,
1–6	16·3	15·0	13·8	12·8	11·9	11·4	10·4	9·6	9·1	8·5	8·1	7·7	,,
1–5	14·0	13·0	11·9	11·1	10·4	9·8	9·1	8·6	8·0	7·6	7·2	6·9	,,
1–4	11·9	11·1	10·2	9·6	9·0	8·5	7·9	7·5	7·1	6·8	6·5	6·2	,,
1–3	9·8	9·0	8·4	7·9	7·5	7·1	6·8	6·4	6·1	5·8	5·6	5·4	,,
1–2	7·5	7·1	6·8	6·4	6·1	5·9	5·6	5·4	5·1	5·0	4·8	4·8	,,
1–1	5·4	5·1	4·9	4·8	4·6	4·5	4·4	4·3	4·1	4·0	4·0	3·9	,,

road work a slump of $\frac{1}{2}$ to 1 in. is permissible ; outside these limits the mixture is either too dry or too wet.

A wet consistency of concrete will show a slump of from 4 to 8 in. Furthermore, it should be noted that crushed stone will show a less slump than concrete of the same consistency composed of other materials, owing to the fact that the angular fragments of the former will be held in place mechanically in the mixture, whereas aggregates having a smaller proportionate area are not held to the same degree.

Mixing of Concrete.

The mixing of concrete for paving work may be carried out either by hand or by machine. As hand mixing is so well known it is not necessary to describe it in detail It is much less accurate than machine mixing, and can only be recommended for small areas of work where it would be uneconomical to transport mixing plant to the site. Another objection to hand mixing is that the consistency of the mixture is likely to vary on account of the unreliability of the men employed. Their tendency is to aim at a mixture which will be too wet, and much more supervision will be necessary than for machine mixing. Therefore, as hand mixing is very much more expensive than machine mixing, it should be excluded from the curriculum of the road engineer for concrete road work.

TRUNCATED CONE MOLD.

Fig. 65.—Romans' Truncated Cone for Slump Test.

The mechanical mixing of concrete has now become so general and the designing of the machines so scientific that no engineer need hesitate to possess one or more mixers as part of his permanent plant. The mixers already on the market may be classed broadly as follows :—

1. Batch mixers.
2. Continuous mixers.

The batch mixer deals with measured quantities of the various ingredients of the concrete, namely, coarse and fine aggregate,

cement, and water, which are delivered into the mixer ; a rotary movement mixes all the ingredients together, which are then completely removed, each change being known as one batch. In the continuous mixer the materials are passed into the machine in a constant stream in their correct proportions and the mixed concrete is discharged at the opposite side. As a general rule the batch mixer is much to be preferred to the continuous mixer for road work as it is more accurate in its results. The mixing of the concrete is mostly carried out in drums of various shapes, such as the cylinder, cube, and the double cone. In the cylinder, blades are usually provided to hold and lift the material in the process of mixing. In the cube and double cone drums the blades are sometimes omitted in order to avoid having to renew them, and also to enable the drums to be more readily cleaned. In these cases the materials are lifted or raised and turned over by friction and centrifugal force.

There is certainly some objection to fixing the blades in a mixer, as they are troublesome to clean and keep in good working condition.

A convenient size of mixer for all-round purposes is one which will mix half a cubic yard of concrete in one operation.

Small mixers have the advantage of turning out the mixture speedily and thus maintaining a constant supply of fairly uniform quality, whereas with the large mixers it may happen that the last portion of a batch is of different strength and consistency from the first portion. The raw materials are gauged and fed into a hopper at ground level, which is then raised to such a position that they deliver into the rotating drum, the outlet of which is closed. Water is immediately passed into the drum and the whole of the contents are revolved until thoroughly mixed together, a process which occupies about 1 min. The speed of rotation depends largely upon the capacity of the mixer. For a mixing of $\frac{1}{2}$ a cu. yd. a speed of 12 to 15 revs. per minute is sufficient. Smaller mixers should be revolved at 15 to 20 revs. per minute.

Treatment of Formation—Placing the Concrete.

The process of placing the concrete in position, although appearing to be a simple operation, is a matter requiring con-

siderable skill on the part of the operators engaged on the work.
As is the case with bituminous road surfaces, uniformity in
subgrade, and in the mixture, thickness, density, and consistency
of the concrete are the principal points requiring special care.
It is comparatively easy to obtain uniformity of this character
during one day's work ; it is much less easy, however, to obtain
it from day to day owing to the ever-changing weather con-
ditions.

The greatest possible attention, therefore, should be given
towards securing uniform conditions with the subgrade. Ground
which shows signs of excessive water should be treated as in the
case of an ordinary macadam road. It is of the highest import-
ance that efficient subgrade drainage should be provided for the
concrete slab to ensure against failure : it is unnecessary to
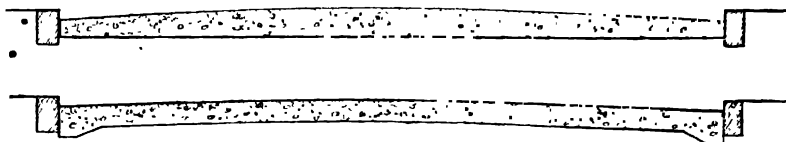
FIG. 66.—Sections of Unreinforced Slabs with Horizontal Base and with
Cambered Base.

elaborate here upon this point, except to say in broad terms that
the engineer must aim at creating as far as possible a subgrade
which shall be consistent in its bearing power, etc.

Generally it will be found of advantage to excavate the ground
to a level which will allow of a cinder bed being laid and rolled
before placing the concrete. The contour of this foundation
should be the same as that of the finished surface rather than
completely horizontal (Fig. 66), since apart from other con-
siderations it is not advisable to make the slab thinner at the
sides than at the centre ; breakings or failure are more likely to
occur at the edge of the road than in the middle, especially in the
absence of kerbs.

The concrete should not be placed in position if the foundation
is frozen or is excessively wet or too dry, as in either case the
consistency or water-content of the concrete will be affected before
the initial set. In the case of a dry subgrade it is perfectly easy

to damp the foundation so that it will neither absorb or exude water when the concrete is placed over it.

The method of conveying the concrete from the machine to the bed depends upon the amount of space available adjacent to the road. Where possible a movable mixer with a delivery arm, as shown in Fig. 67, which can be run alongside the road, will be found to be the most convenient and economical machine. Another method of utilizing the delivery arm for distribution is to place the mixer in the centre of the road and move backward from the completed work.

In congested areas, however, this is sometimes difficult if not impossible, and other methods of transporting the mixed concrete have to be devised." In such cases the concrete may have to be transported on small trucks and rails or handcarts; sometimes, indeed, the wheelbarrow must be utilized as a last resort.
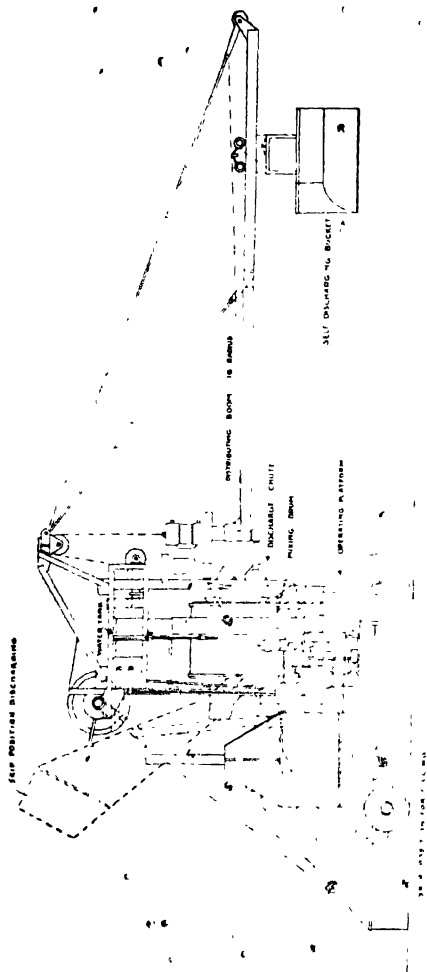
Fig. 67.—Batch Concrete Mixer with Self-discharging Bucket.

Monolithic Work Essential.

It is of the greatest importance that the concrete slab, whatever its number of courses, should be *absolutely monolithic*, and that the work be carried through progressively and finished at the end of the day at some definite point. With two-course work composed of a richer and finer concrete in the top layer than in the bottom the two separate mixings of concrete should be carried out simultaneously, so that the deposition of the coarse concrete precedes slightly that of the wearing course ; the latter will not be more than 2 or 3 in. thick as a rule, so that if laid in this manner the whole slab becomes one mass ; in other words, the whole depth of concrete will solidify together. In no case should more than 45 min. elapse between the time of mixing the base course and the time of placing the wearing course.

Templates and Tampers.

The templates for shaping the road longitudinally and transversely must be fixed with the greatest possible care. Where a longitudinal fall exists the templates may be fixed at either side of the road and the surface formed by means of the cambered tamper to span the space between the templates. The templates may be constructed
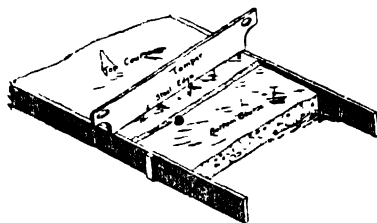
Fig. 68.—Hand-Tamper for Tamping between Two Forms.

with timber, steel beams, or channels, or old tram rails, which must be firmly fixed, as upon this depends the gradient and finished level of the road.

Where the road is not particularly wide, the tamper can be handled quite easily by men on each side of the road. It is an advantage to have a heavy tamper rather than a light one, but this of course imposes a considerable strain on the operators and additional assistance becomes necessary.

The object of tamping is to enrich the upper layer of concrete, to remove the voids and thereby render the wearing course as

dense as possible ; and a heavy tamper accomplishes this with greater certainty than a light one. The tamper may consist of a board about 9 in. by 1½ in., steel shod on the lower edge (Fig. 68). It is raised up and down off the templates quickly, the movements decreasing from heavy taps to light laps on the concrete towards completion.

The shaping and tamping of the concrete can be more easily carried out by a mechanical device, known as a tamping template or tamping machine.

Tamping by Machine.

A complete outfit for this machine comprises a concrete mixer, a tamping template driven by a petrol engine in the centre of the framework with clutches and levers to regulate the speed ; small steel cables winding round drums on the template are carried to steel stakes ahead, in order to draw it steadily and evenly forward upon template rails at each side of the road as the work progresses. Two clutches on the drums operate independently, so that the template can be worked on curves. The mechanism is such that some 60 to 70 light vertical taps from the tamper are delivered rapidly to each portion of the concrete covered. The concrete is first placed in front of the machine, roughly levelled, and the tamper finishes the work. In some cases the machine operates a belt for finishing the surface.

Where roads are very wide or very flat longitudinally the arrangement of the template may require modification : where gullies are placed in the channel itself the usual artificial gradients will, of course, alter the shape of the road somewhat from point to point.

The use of transverse templates or bay construction is not to be recommended, although it lends itself to this particular flat type of road ; for this purpose wooden templates of varying cambers are fixed transversely at intervals of 12 to 15 ft. The template opposite the gully is shaped with a quick curve near to the channel, while the one half-way between the gullies shows the least camber ; great care is necessary to ensure that the middle portion of the road is uniform throughout. The bays are filled and tamped alternately and then allowed to set for 3 or 4 days,

after which the wooden forms are removed and the remaining bays tamped in between the filled bays.

One of the principal objections to this form of construction is the great frequency of transverse joints and the absence of density in the concrete at these joints.

A very much simpler method, and one which has many advantages, is that of providing a longitudinal side template or utilizing the kerb and also a centre one. This forms a longitudinal joint down the centre of the road, as in Fig. 68A, and is regarded by some engineers as a source of weakness. On the other hand, some authorities consider that a longitudinal joint is good practice. It is obvious that this method of construction would enable a road to be kept open for traffic—a factor of great importance in all road work.
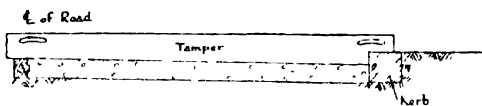
FIG. 68A.—Hand-Tamper for Tamping between Centre Template and Kerb.

On flat roads, where " summits " in the channel are necessary, the middle portion of the road is tamped to constant shape from centre template and kerb. The channel may then be laid and floated to its true gradient and the remaining portion of the wearing course tamped in between channel and centre portion before the concrete has taken its initial set. It is essential that the tamper should have an increased bearing surface where it rests on the channel and centre sections.

Expansion and Contraction Joints.

In the early history of the concrete road expansion joints were placed at distances of 25 ft. or thereabouts, but in the light of subsequent experience the distance between such joints has been lengthened until now stretches of 200 to 300 ft. are the rule ; in other words, no special provision for joints need be made other than that which naturally occurs at the completion of one day or half a day's work as the case may be.

Concealed joints have been used to dispense with the surface

joints. These are formed by placing a strip of weather-board, ½ in. thick, against the face of the previous day's work, the top of the board being 3 in. below the surface of the pavement at the centre. The result shows that only a thin crack develops at these points and that they are easily treated with hot bitumen. Recent tests in America show that the edges of a concrete slab turn downwards as the atmospheric temperature rises, and that they turn upwards with a rapid fall in temperature ; a cool rainfall, for instance, will produce the latter effect. It is a distinct advantage in placing joints to arrange that they are not quite at right angles to the direction of the road, as shown in Fig. 78. By this means the wheels of motor vehicles only cross one at a time, and the impact and periodic vibration of the vehicle is very much reduced ; also, expansion can take place by the slabs slipping along the joint.

Several methods of securing these joints against vertical movement have been tried with varying success. Longitudinal reinforcement is recommended to prevent contraction, whilst steel dowels having one half covered with brown or tar paper fixed at the joints will admit of expansion. Corrugated metal strips, 6 to 12 in. wide, with ⅝-in. round bar dowels passing through transversely at intervals have been laid along the joint at the centre of the road and at transverse joints to prevent cracking ; also longitudinal bars, ¾ in. diameter, laid within 6 in. of and parallel to the edge of the slab to strengthen the edges and to assist in preventing transverse cracking have been used with . success.

Another method which has answered the purpose is to lay the base course continuously and to form joints by alternate bay construction in the wearing course only. This prevents a truly monolithic slab being formed, and its success depends upon the wearing course being not less than 2½ or 3 in. thick, and the surface of the base course being left very rough to form a key for the top course.

'Finishing the Slab.

The finishing of the concrete surface is a process requiring careful supervision and considerable skill on the part of the

operators. In many cases tamping is considered sufficient to provide a regular surface which will not be too smooth. Surfaces may also be finished by floating from a bridge with wooden floats, by rolling transversely with a long-handled or rope-drawn roller, 6 in. diameter and 6 ft. long, weighing about 100 lb., until water ceases to come to the surface ; or by belting with a canvas or rubber belt—transversely and with a see-saw movement—not more than 12 in. wide with sticks nailed across the ends for handles. These processes compress the concrete, reduce the voids, and force out the surplus water.

Fig. 69 shows surfacing floats which are manipulated by a long
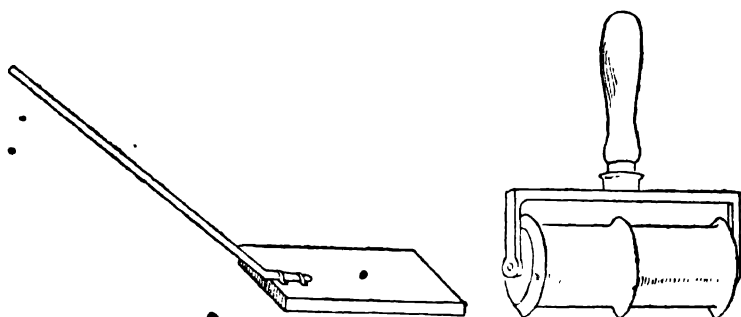
Fig. 69.—Surfacing Float for finishing and Impression Roller for grooving Concrete Paving.

handle, and an impression roller for grooving concrete paving ; the roller is used after the concrete has taken its initial set.

Curing and Protection.

After the finishing of the concrete surface it is necessary to take further steps to obtain a hard-wearing pavement. In the first instance some protection from animals, and in town districts also from children, until the concrete has set hard enough to bear such weights, is essential, and close fencing may become a necessity. Wire-netting or split oak fencing are very suitable for this purpose. In hot sunny weather the concrete should be protected by placing canvas or tarpaulin shades over it. Heavy rain is likewise detrimental to the newly finished concrete, and it is difficult to provide cover that will protect it at all points.

When the concrete is sufficiently hard, i.e. after about 2 or 3 days, it should be " cured." for a period of 2 to 3 weeks by keeping the surface continuously moist. This is absolutely essential to obtain a hard surface. It may be effected by " ponding "—a process of building clay dams at the sides and across the road to retain a depth of about 2 in. of water, or by covering with a 2-in. layer of earth which is kept continuously wetted for the specified period, or it may be sprinkled with water only ; the latter method is, however, the least satisfactory.

In hot weather the crown of the road—which, of course, has the greatest wear—dries very quickly both after laying and later after sprinkling, and curing is rendered ineffective for the middle portion of the road. In this manner the wearing qualities may be seriously impaired where traffic is the heaviest.

Traffic should not be allowed to pass over the road until a period of at least 2½ weeks has elapsed from the laying of the last section in mild weather, and for a longer period in cold weather. This closing increases the cost of the work by the additional watching and lighting. In some cases it would be advisable to close the road after, say, 2 weeks only during the daytime and open it during periods of darkness. This dispenses with lighting and also night watching.

In late autumn or early spring when frosty nights are possible great care is necessary to prevent a sudden fall of temperature from injuring the concrete. A layer of straw, straw matting, or similar material applied to the surface will prevent freezing. As a general rule, concreting should not be permitted in frosty weather under any circumstances. The use of the quick-hardening cement known as " bauxite " or " ciment fondu " may be advantageous in opening a road to traffic in cases of urgency.

Re-surfacing Concrete with Reinforced Concrete.

Where a concrete pavement has worn out or a foundation failed, it is quite practicable to re-surface with an independent slab of reinforced concrete. Where this is done the defective surface should be levelled up with concrete and afterwards coated with tar, so that the new slab will be free to expand or contract independently of the old one.

The thickness of the new slab should be not less than 3 in. and the mesh reinforcement not less than 30 lb. per 100 sq. ft.

In a case which came to the Author's notice recently the concrete foundation under granite sett paving had failed, and the method of reconstruction adopted was to break up the old concrete, replace it with new concrete, reinforced and paved with new granite setts. Had the old setts been replaced with a 7-in. reinforced concrete slab surface a very large sum of money would have been saved.

Re-surfacing Old Concrete with Bituminous Wearing Course.

Where concrete has become worn it may be utilized, with advantage, as a base for a bituminous wearing surface which, of course, may be renewed or repaired from time to time with considerable ease. In order to do this it is necessary to raise the channels or build an additional strip of concrete to the height of the new road surface, as shown in Fig. 70; as an alternative to this sett or cobble paving could be employed with economy in some cases.

Surface Dressings Unsatisfactory.

It is unnecessary to apply tar or bituminous dressings to a well-constructed concrete road, as they will not adhere evenly and in some cases will not adhere at all. Consequently the surface wears in patches, or becomes wavy, and in wet or frosty weather it works up into a muddy surface.

Central Mixing of Concrete.

The Bureau of Public Roads, U.S.A., have conducted an experiment to determine the maximum safe distance for haulage of centrally
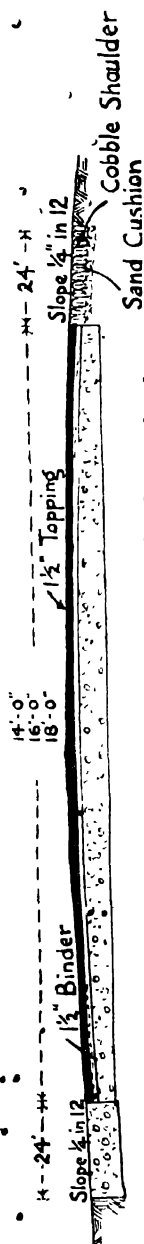
FIG. 70.—Old Concrete Road Widened and Re-surfaced.

mixed concrete. Two batches of 1 : 1½ : 3 concrete were mixed
to a consistency having a slump of 2 in. It was divided
into six equal portions, which were sampled for crushing
strength at varying periods up to 3 hours. Up to 2½ hours
it was possible to handle the concrete with a shovel, but after
this it became necessary to use a pick. The concrete became
very dry after 1 hour's haulage, but the crushing strength was
not seriously depreciated, and although too dry for hand-tamping
after 45 mins. it was found satisfactory for use by a finishing
machine at any period up to 2 hours after mixing.

It is stated that central mixing can be utilized in conjunction
with a road-finishing machine with satisfactory results, and
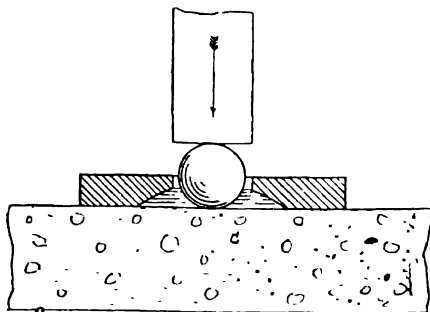
Fig. 71.—Ball Test for Hardness of Concrete.

provided the concrete is workable the strength will not be
affected.

Ball Test for Surface Hardness.

This test, recently devised, consists of placing a ½-in. steel ball
in a holed steel plate 2′ × 2′ × ¼″ on the concrete surface, as shown
in Fig. 71, and applying a load by means of a motor lorry and
jack. The ball is thus pressed into the concrete and the loads
registered until the ball has penetrated ¼ in. when the load comes
directly on to the plate. The test is very simple, and is useful
for determining whether the curing process has been satisfactory
or not, and whether the surface is sufficiently hard to withstand
steel tyres of heavy traffic.

Examples of the Use of Concrete for Improving Roads

1. Widening at Bends.

This has already been alluded, to in an earlier chapter. Concrete is exceptionally suitable for widening or improving the superelevation at bends; it can be laid on the inside or outside of the bend as a mere addition, leaving the old roadway almost untouched. Thus a concrete strip supporting the edges of the existing road metal is obtained. Outside widening, together with superelevation at a bend, may prove a most valuable improvement where inside widening is impossible.

2. Widening Narrow Macadam Roads.

As shown in Figs. 50, 51, and 52, concrete strips may be laid at each side of a narrow road without disturbing the surface, except perhaps by re-surfacing with new macadam or bituminous wearing course. In such cases the camber may be reduced by raising the concrete strips or channels about the edges of the old macadam.
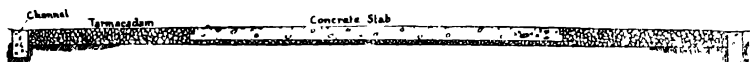
FIG. 72.—Centre Strip of Concrete with Macadam Haunches.

3. Centre Strip of Concrete.

In many cases it will be a distinct advantage to substitute for a worn carriageway a centre strip of concrete about 10 or 12 ft. wide, making good the adjoining haunches with tar-treated material, or old sett paving as the case may be. This provides a good road for the bulk of the traffic, and it is only in passing each other that the side surfaces come into operation. In addition, a concrete channel on either side may be laid to strengthen the haunches (Fig. 72).

4. Separate Strips of Concrete.

This method may be adopted partly for convenience in laying and partly to provide separate tracks for traffic in each direction —and is only possible for wider roads. The centre or dividing strip may be laid in asphalte or other bituminous surfacing.

The separation of traffic is an important feature of this design (Fig. 73).

5. Laying Concrete, One Half only.

As a means of economy, or widening, this method is commendable, because one side of the carriageway may remain undisturbed and a greater length of new work provided for a given expenditure than if the whole width were relaid. At a later date, of course, the other half may be laid in concrete. In many cases the old macadam may be scarified and utilized as
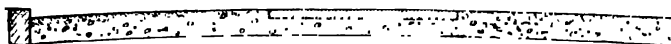
FIG. 73.—Separate Strips of Concrete with Asphalte Centre Strip.

aggregate for the bottom course of the concrete. It is more advantageous to do this than to lay a thinner slab on the undisturbed macadam. Fig. 74 shows this method of construction with strengthening at the centre and at the channel.

Brief Specification for Concrete Paving

The following brief specification is given as a guide for the preparation of more detailed specifications for a particular work :—

The existing ground shall be excavated to the level and formation required by the Engineer.
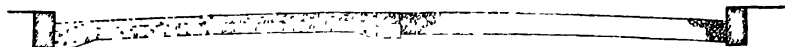
FIG. 74.—Half Width Concrete and remainder Macadam.

The concrete paving shall be 6 in. in thickness when complete. It shall be composed of a 4½-in. bottom layer of concrete, 3 parts broken stone of gauge between 1½ in. to ¼ in. limits, 2 parts clean sharp sand graded between 0—¼ in. and 1 part of Portland cement, or thereabout, as determined from Abrams' table of proportions. The top layer or wearing course shall consist of 1½ in. thickness of concrete of 2½ parts of granite chippings of gauge limits ¾ in. to ¼ in. to 1 of granite dust of 0—$\frac{1}{14}$ in. and 1 of cement verified from Abrams' tables to produce a 4 : 1

mixture as nearly as possible, which shall be placed on the 4½-in. layer whilst same is still wet, so that the whole thickness forms one homogeneous mass. The top layer shall be brought to a smooth-finished level in accordance with the shape and heights agreed upon by the Engineer. The concrete shall not be applied upon a very wet or very dry foundation, and it shall be mixed without a surplus of water. If required the Contractor shall prove his proportions from time to time by the method of voids.

The materials and appliances for mixing and depositing the concrete must be scrupulously clean in every case. The broken stone or chippings must be graded and tested for voids, and the sand tested for tensile strength as required by the Engineer. The aggregate must be composed of cubical and not flat particles.

The method of construction shall comprise essentially the fixing of templets, at least 7 in. by 3 in., sufficiently rigid so that the concrete may be paved between them, and tamped to a smooth finish with a steel-shod straight-edge working on the templets, and allowed to set for 2 or 3 days ; after this period the templets may be removed and refixed, and a further length paved in with concrete and finished by tamping as before.

The whole of the concrete shall be protected during the progress of the work with suitable close fencing so that dogs are prevented from crossing the wet concrete and spoiling the finish. Otherwise the fencing shall be high and strong enough to prevent mischievous persons trespassing on the site of the concrete. The concrete shall be kept continuously wetted for a period of 14 days, either by watering alone or by wet sand or earth. The concrete shall also be protected from frost during period of setting.

No portion of the road shall be opened to traffic until it has been laid for a period of 2½ weeks.

Where reinforcement is laid a supplementary specification will be supplied.

CHAPTER XII

REINFORCED CONCRETE

IN the preceding chapter the question of reinforcing concrete has not been dealt with in detail. The addition of reinforcement to any road slab increases considerably its power of resistance to traffic, wear, and weather. The advantages of reinforcement are as follows :—

1. Increased Resilience of the Slab.

Resilience is a valuable property for any road to possess ; in the same manner a cushion foundation is of advantage to a railway. A resilient concrete slab should offer better wearing qualities than a surface which is either non-rigid or non-resilient.

2. Increased Distribution of Wheel Load on the Subgrade.

Generally speaking, a reinforced concrete slab 6 in. in depth will spread any wheel load for an area of 10 sq. ft. of ground, although the pressure on this area is not uniform. This distribution of load to the foundation makes it possible to lay concrete with security and safety, even on a soft subgrade.

3. Prevention of Cracking.

The increase of strength gained by the slab from the addition of reinforcement enables the thickness of the concrete to be considerably reduced. In fact, the unreinforced slab may not give the same support even when twice the thickness of the reinforced slab. Generally, the reduction of 2 in. in the slab will pay the cost of the reinforcement. A further saving may be effected in the amount of excavation required—an important consideration when roads are being remodelled. The unreinforced road cracks more readily than the reinforced road.

The subsidence of earth filling is a process which continues for many years, and it is impossible to say when this subsidence has finally ceased. The reinforced slab removes anxiety which may be felt on account of disturbance of this nature in the early life of the road. Cracking is due also to contraction stresses being set up in the concrete itself, owing to the natural contraction of the cement, changes in temperature, or variation in the percentage of moisture in the slab. The provision of reinforcement distributes these contraction stresses, so that the possibility of cracks developing is reduced to a minimum.

Resistance to Warping.

Another feature of the reinforced slab is its resistance to warping ; the unreinforced slab being so liable to crack, it is necessary to provide expansion joints to limit this cracking. Concrete and steel expands and contracts equally, thus distributing stresses over a very large area so that joints may be either quite unnecessary or at very infrequent intervals.

It has been noted elsewhere, in the chapter on "Reinstatement," that the use of the reinforcement enables the foundation or wearing slab to be laid shortly after a disturbance of the road or subgrade for the laying of mains, etc. Reinforcement is a sheer necessity in such cases, as also it is where any defective foundations exist. From being an inert mass, therefore, concrete becomes, with the introduction of steel reinforcement, an elastic body. As previously mentioned, in cases where a concrete road has become badly worn it has been successfully re-surfaced with a thin slab of, say, 2 to 3 in. of reinforced concrete. The presence of the steel compensates for the non-monolithic slab and prevents " shelling " or cracking of the wearing surface.

The question of the particular reinforcement to be adopted is best left to the discretion of the engineer. It is proposed to describe two of the principal reinforcements used in road work.

British Reinforced Concrete Company's (B.R.C.) Fabric.

This fabric is manufactured and supplied in rolls by the British Reinforced Concrete Engineering Company, which firm is properly entitled to rank as the " pioneer " in reinforced

concrete road work. Other fabrics have been placed on the
market either similar to this or in the form of expanded metal.

Standard rolls of this wire (Fig. 75) are 240 ft. long by 7 ft.
wide. The heavier wires run longitudinally and the lighter wires
transversely. The whole of the interlocked sections of trans-
verse and longitudinal wires are electrically welded, as shown in
Fig. 76. The fabric frequently used for road work is a No. 9,
which consists of longitudinal wires of No. 5 gauge, 3-in. spacings,
and transverse wires of No. 10 gauge to 12-in. spacings, as in
Fig. 77. The effects of welding the wire intersections permits
the stress from the heavier wires to pass to the transverse wires,
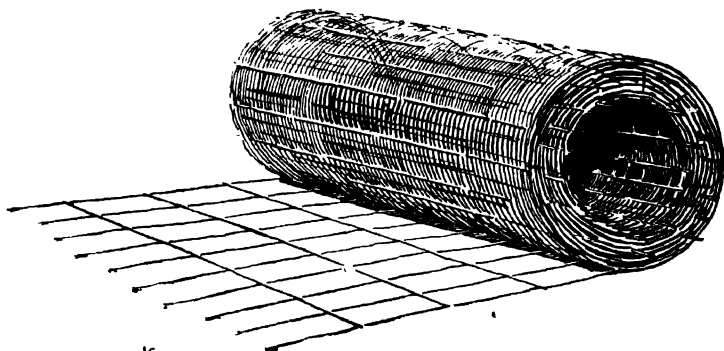
Fig. 75.—Roll of B.R.C. Fabric.

which are anchored into the concrete in a transverse direction.
It will be seen that any local stress in the steel, due either to
loading or contraction, is quickly distributed to the surrounding
steel, at the same time making use of the compressive resistance
of the concrete.

Where narrow trenches have been reinforced, it is desirable
to lay the heavier wires across the trench rather than longi-
tudinally. Special cutting shears are used to cut off the reinforce-
ment to the desired length. These shears are comparatively
inexpensive and quickly pay for themselves.

A lighter fabric may be laid if desired in the upper portions of
the concrete, the heavier section being laid 1 to 2 in. above the
bottom of the slab and the lighter section about 1½ to 2 in. from

the surface. It is well known that, particularly in the case of a
wide road, secondary stresses are set up in the upper layer of the
concrete due to the complexity of the surface traffic, and where
this happens reinforcement will impart the necessary strength
to the slab.

In addition to this it assists in resisting the contraction
stresses caused by the joints and the changing temperatures at the
surface, whilst the base of the slab has a more or less constant
temperature. These fabrics are supplied in varying weights
according to the particular road conditions encountered. Where
work is left overnight, it should be finished with a straight or
stepped vertical edge across the road, and an extra strip of
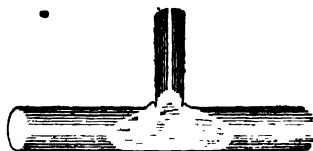
FIG. 76.—B.R.C. Fabric showing   FIG. 77.—B.R.C. Fabric showing Longi-
the Weld between Longitudinal   tudinal and Transverse Wires.
and Transverse Wires.

reinforcement 3 ft. wide may be inserted about 2 in. below the
top of the concrete, half the width being built into the day's
work, leaving the other half, 18 in. projecting, to bond the next
day's work.

Where a road is laid in two halves, for the convenience of the
traffic, the joint along the middle of the road may be finished
against a board with a straight vertical edge without any
reinforcement projecting. The second half of the road should be
finished up against the first half, with just a thin layer of felt
between, extending the full depth of the concrete. This keeps
the two halves entirely separate and allows the newer concrete
to contract and move freely without being restrained by the
older concrete which has already contracted. To facilitate the
placing of the felt, small wood dowels may be inserted in the

vertical edge of the first half, not nearer to the surface than 2 in., to which the felt may be nailed. Care must be taken to keep the edge of the first half exactly level with the second half.

An alternative method is to finish the edge of the half-slab with a row of setts, making the concrete 6 in. thick below the setts and for a 12-in. width adjoining them. The setts should be laid when the concrete is wet and grouted with fine concrete.

Walker-Weston Reinforcement.

This method of reinforcement, designed by Mr. J. Walker, A.M.I.C.E., was the outcome of the previous difficulty foreseen in laying a satisfactory concrete road upon soft ground. The reinforcement provides for top and bottom layers of reinforcing bars, combined with zigzag diagonal tension members, in such a manner as to form a rigid mattress to which any additional bars may be attached as required (see Fig. 78). The steel is delivered straight to the site in coils of $\frac{3}{16}$-in. diam. wire and straight lengths of $\frac{1}{4}$-in. or $\frac{5}{16}$-in. bars. The men then bend and assemble the bars on rough benches, which are moved forward with the work.

The advantages claimed for this type of reinforcement are :—

1. Economy.

2. To provide two layers of reinforcement to meet the flexure and contra-flexure in the slab imposed by traffic.

3. To eliminate the provision of expansion joints and to prevent cracks.

4. The pyramidal diagonal bars being anchored in the bottom layer of the concrete spread any contraction over innumerable hair cracks.

After the road bed has been excavated and graded, the reinforcement is laid thereon, the bottom concrete, 1 to 2 in. thick, being laid in position, and the reinforcement lifted through it, by hooked bars, so that it rests on the concrete. The remaining 5 in. of the bottom 7-in. coat is then deposited. The top 2-in. coat is then placed in position, tamped, and screeded by a specially constructed screed worked by two men to the correct contour required. Fig. 79 shows the method of alternate bay construction with slanting transverse joints, details of which are given in Fig. 80.

Raft extended 18 inches beyond
Channel to provide bearing for
loads travelling in Channel
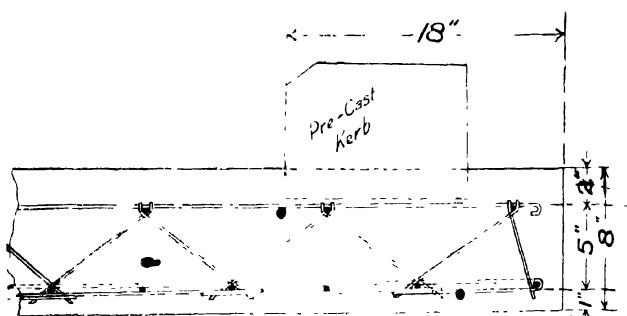
reement.
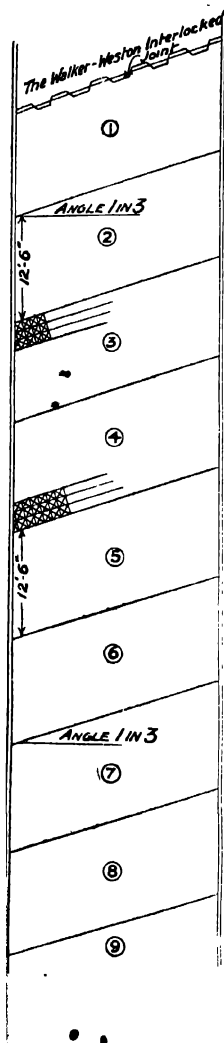
FIG. 79.—Plan of Walker-Weston Reinforcement with Alternate Bay Construction.

The Walker-Weston Interlocked Joint

① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

ANGLE 1 IN 3

12:6"

ANGLE 1 IN 3

PATTERN A = 10 lbs to the Square Yard
" B = 14 " " "
" C = 17 " " "

CROSS SECTION ON LINE A-B.

CROSS SECTION ON LINE C-D.

SIMPLE FORM OF STUNT END BOARD

5"x2" Spiked to 8"x3"
8"x3"

5"x4" in loose lengths
of 2 ft. spaced at 4'-0"
Centres.

KERB

A B C D

4'-0"
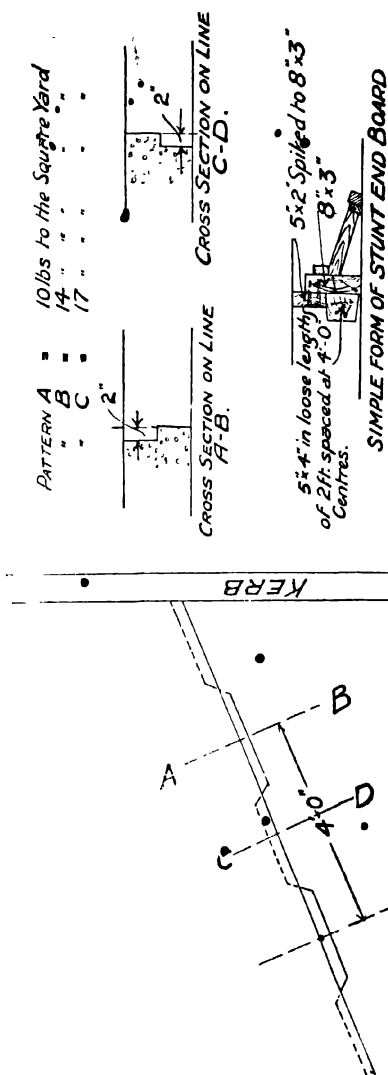
FIG. 80.—Details of Alternate Bay Construction.

Other Methods of Strengthening Joints, Edges, and Corners of Slab.

It is unnecessary to describe here other proprietary systems of reinforcement. Various examples of the use of simple reinforcement in connection with concrete-surfaced roads may be mentioned briefly. The necessity for strengthening the edges, corners, and joints may be met by the insertion of extra steel, as

CROSS SECTION
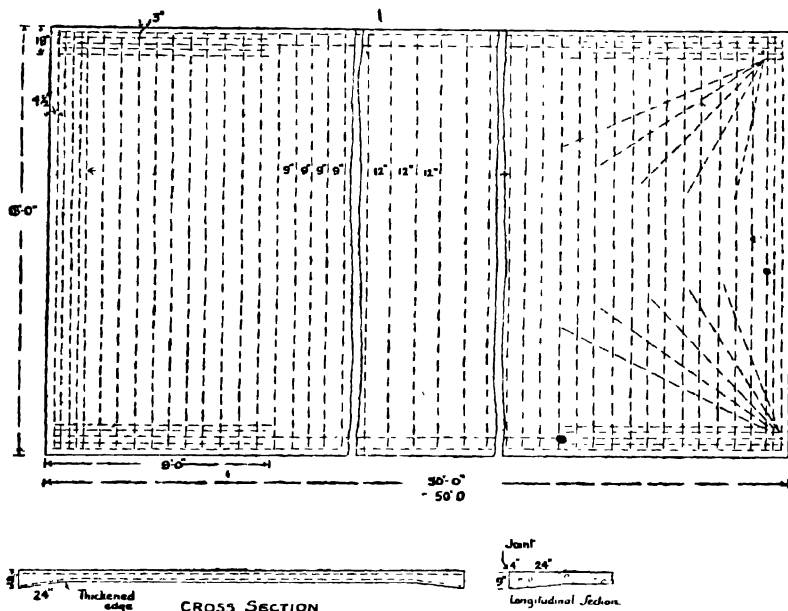
FIG. 81.—Method of Strengthening Edges and Transverse Joints with Additional Steel.

shown in Fig. 81. It is exceedingly desirable to give special attention to this question, as slab fractures usually occur at these points. Without reinforcement, however, strengthening may be effected by increasing the thickness of concrete at the edges and joints.

Another method of strengthening a slab is to lay reinforced concrete beams V-shaped across the joint, as shown in Fig. 82. An alternative to this is shown in Fig. 83, where the V-beam runs
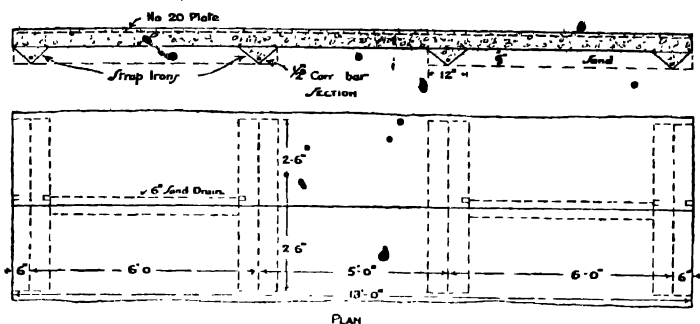
FIG. 82.—Method of Strengthening Transverse Joints by Longitudinal V-shaped Reinforced Beams.
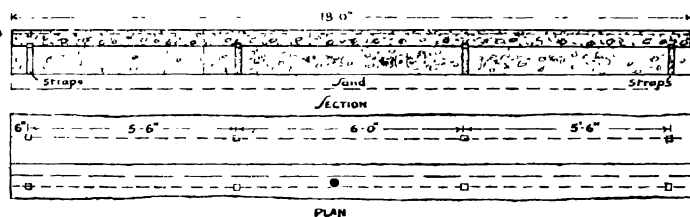
FIG. 83.—Method of Strengthening Transverse Joints by Transverse V-shaped Reinforced Beams.
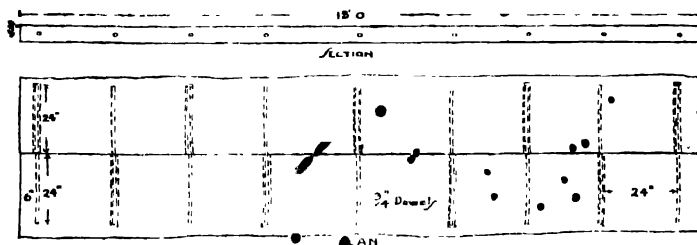
FIG. 84.—Method of Strengthening Transverse Joints by Steel Dowels.

transversely under the joint and is anchored into the slab by means of strap irons.

Steel Dowels for Transverse Joints.

It has been shown elsewhere that steel dowels have been used with success at transverse joints where one half is left with freedom to move independently of that side when expansion or contraction takes place. This may be accomplished by wrapping one half of each dowel with ta · paper or covering it with a coat of some other suitable material and inserting the dowels, as shown in Fig. 84.

Use of Reinforcement for Wheelers.

The Author has used B.R.C. fabric in connection with the laying of two concrete wheelers (see Fig. 5) in the centre of the road, between which grit setts were paved on the fabric and then grouted with cement to the surface; thus the wheelers and paving combined form one complete reinforced slab over 7 ft. wide, which is sufficient to accommodate wide vehicles. The result of this improvement proves that traffic will invariably follow the wheelers, and that they are well able to support the heaviest vehicles at speed and provide smooth running. In the wheelers only single or bottom reinforcement has been used, and contra-flexure, if it exists, has not affected the surface concrete in any way.

In general, it may be said that reinforcement in concrete work for road purposes is both desirable and economical. The question of reinstatement of reinforced concrete for pipe trenches is dealt with in Chapter XVII on " Reinstatement."

Design Features of the Lincoln (U.S.A.) Highway "Ideal Section"

This section of the Lincoln highway (Fig. 85), 1½ miles long, recently completed, lies between the towns of Dyer and Schererville, Lake County, Indiana, which site was specially selected on account of favourable topography and close proximity to Chicago. The general specification and requirements were determined after careful consideration of the replies to 4600

questionnaires sent out to high-
way engineers and college pro-
fessors in highway engineering.
The leading features of the new
road are :—

A complete width of 100 ft.,
including allowance for widening,
and a 40-ft. width of reinforced
concrete paving in continuous
slab construction, providing for
4 lanes of traffic.

The design provides for a
maximum load of 800 lb. per in.
width of tyre and of 8000 lb. per
rear wheel, for which standards
legislation is anticipated.

The drainage consists of sub-
merged longitudinal drain tile and
catch basins.

The concrete pavement is 10
in. thick of 1 : 2 : 3 mixture,
reinforced with 8 lb. of steel per
100 sq. ft., to prevent cracking ;
tie rods are placed across the
longitudinal centre joints and the
transverse joints which are at
75-ft. intervals. Earth shoulders
5 ft. wide and covered with grass
adjoin the concrete.

The section is lighted with
250-c.p. electric lamps at 250-ft.
centres and 35 ft. high. Curves,
where unavoidable, are to be
not less than 1000-ft. radius and
superelevated for a speed of 35
m.p.h.

The footpath is on one side of
the road only.
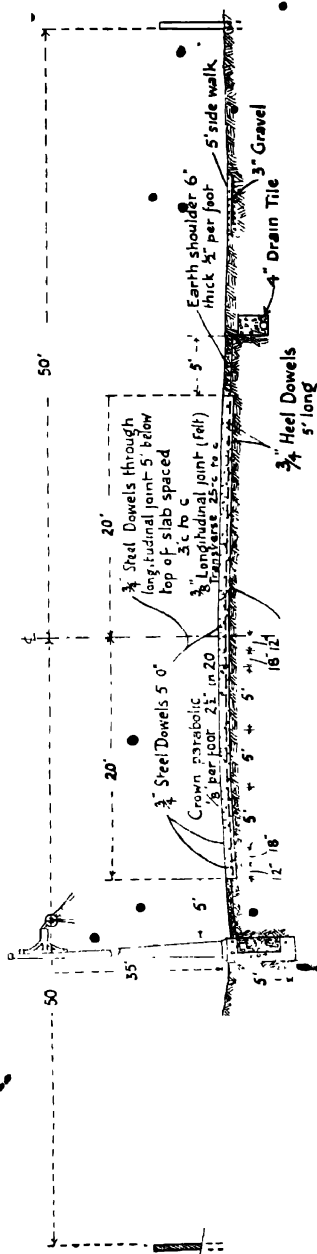
Fig. 85.—Section showing Lincoln (U.S.A.) " Ideal " Highway.

Concrete guard rails on embankments and warning signs are provided throughout.

Gradients at rail crossings are eliminated, and clear vision at intersections of 500 ft. each way is provided wherever possible.

Electric wires ultimately are to be placed underground and advertising signs prohibited.

The mile posting is measured from the municipal head-quarters of any town or city, and comfort stations, park sites, and ideal camp-site facilities provided en route.

The highway will be maintained by the State Highways Department of Indiana.

CHAPTER XIII

UNLIKE road paving the construction of footways has not materially altered during the last decade. Its importance is considerably greater in the town than in the country. For convenience, kerbing, channelling, and footpath surfacing will be dealt with as one subject in this chapter.

Kerbing and Channelling.

The primary uses of the kerbstones are :—

1. To assist in taking the thrust from the carriageway.

2. To assist in guiding the surplus water from roads and sidewalks into gulleys.

3. To define, support, and protect the footpath.

Where natural stone is in question, the choice lies between grit rock and non-slip granite. The dimensions of the kerbstone vary according to the type of road under construction, and the facilities for obtaining material within easy distance.

The kerbstones may be laid with the broad face upwards, or in the form of an edging with the narrow face upwards. In the first case the dimensions commonly given are 10 to 12 in. wide and 6 to 8 in. thick ; as edging, the width would be 6 to 8 in. and the depth would be 10 to 12 in.

A slight variation in the length of the kerbstone is not material, but in no case should it be less than 24 in.

The kerb face should be tooled to the inclination of the footpath, and the front face, joints, and edges tooled straight.

The kerbs may be laid on a 4-in. bed of cinders with the joints set in mortar or, if greater strength is required, as for instance in narrow or busy streets, they should be laid on a 4-in. concrete foundation.

Concrete Kerbing and Channelling.

This type of kerbing has become increasingly popular in the past few years, mainly on the grounds of economy and the difficulty of obtaining natural stone during the War. The kerbing may be pre-cast, preferably in iron moulds, or formed in position on the site ; or the kerb may be built integrally and bonded with the concrete pavement or with the channel, as shown in Fig. 86 ; the methods of construction are clearly indicated.
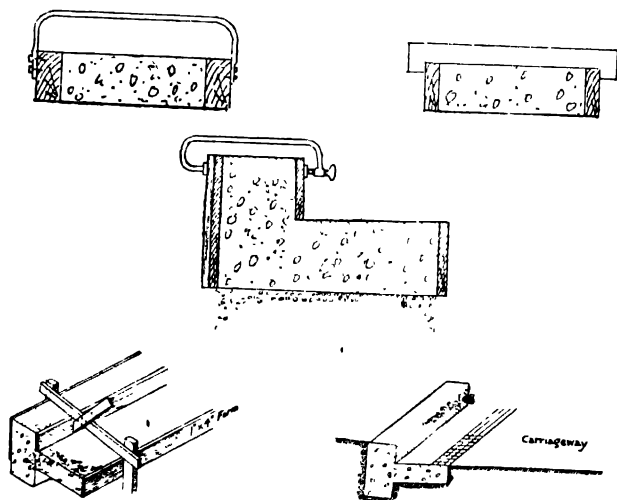
FIG. 86.—Methods of Construction of combined Concrete
Kerb and Channel in situ.

The composition of the concrete must be such as to provide a reasonably fine finish ; the concrete should be 3 or 4 to 1 and the aggregate of granite chippings graded from $\frac{1}{4}$ in. down to dust and preferably reinforced with two light rods.

The usual precautions for moulded concrete must be strictly observed. Where the kerbs are pre-cast they should be laid upon a concrete bed, as in Fig. 87, in order to provide additional strength to resist wear and impact.

Channel blocks have in the past been usually formed of granite, but pre-cast channel blocks in concrete, laid upon a

concrete foundation, or laid in situ on main roads, are now popularly used.

Submerged reinforced concrete kerbs moulded in situ may be laid along the channels on country roads to take the thrust from the carriageway.

Another method of utilizing concrete for kerbs is to cast the concrete with a suitable piece of flat or angle iron on the side and edge exposed to traffic. This is readily accomplished, as shown in Fig. 88. Particularly in congested cities or on the down-side of a hill, where horse vehicles use the kerb as a brake, is iron edging desirable.
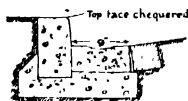
FIG. 87.—Pre-cast Concrete Kerb and Channel laid on Concrete Foundation.

FIG. 88.—Concrete Kerb combined with Iron Plate to resist Wheel Grinding.

Flagging.

This method of surfacing for footpaths is probably the most satisfactory from all points of view. In particular it is the most suitable, having regard to reinstatement difficulties after disturbance.

It consists of two types :—

1. Natural flagging.
2. Artificial flagging.

Natural flagging is usually taken from gritstone formations ; it has a non-slippery surface, is strong, and practically waterproof.

Artificial flagging is cheaper and of better appearance than natural flagging, and in consequence has largely superseded it. Generally natural flagging is indispensable for steeper gradients owing to its non-slippery nature, although some varieties are slippery ; in any event, it may be necessary to mark the slabs with cross grooves to assist the foot-grip of pedestrians.

Artificial flagging is generally composed of rectangular or square pre-cast concrete slabs of thickness from $2\frac{1}{2}$ to 3 in. The

size varies from 2 to 3 ft. in length with a 2-ft. gauge between the
straight joints.

The flags are laid to a bond which will give a break of joint of
not less than 6 in., as shown in Fig. 89. The straight joints are
generally transverse to the line of the kerb, but occasionally they
are preferred longitudinally and are useful for reinstatement over
pipe trenches. Jointing is done by pointing with good lime
mortar. The flags are laid with a cross-fall of about 1 in 36
towards the channel. Artificial flags are usually constructed
without reinforcement ; this is usually considered unnecessary
as the stresses which occur on footpaths are not very severe.
Artificial flags, composed of 4 : 1 concrete, should sustain upwards
of 1 ton concentrated load on a span of 2 ft. The addition of a
light reinforcement increases the
bending strength of the slab, pre-
vents cracking, and enables a
lighter slab to be used if desired ;
also, it enables the flags to be
moulded by hand, locally, and
dispenses with the process of
hydraulically (or other means)
pressing the wet concrete, as is
done by large manufacturing firms.
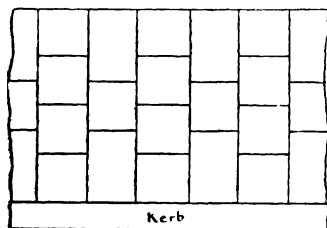
Fig. 89.—Bond of Artificial
Flagging.

The Author has made such flags at a cost of 50 per cent less than
the manufacturers' pressed flag. The face of the slab should be
composed of a mixture of 3 parts granite chippings and granite
dust or sand to 1 of cement.

Bedding of Flags.

All flags should be solidly bedded on a 3 or 4-in. layer of fine
cinders or sand. Mortar may be used to assist in bedding the
slabs, although it is not a necessity. The joints should be as
close as possible and space filled with good-quality mortar.

Lifting Artificial Flags.

The necessity for lifting flags for the purposes of laying mains,
etc., makes it essential to provide against damage to the flags by
" chipping " from crowbars. This may be accomplished by

inserting at intervals a special flag containing two small iron rings, by means of which the flag can be levered out by the aid of rods or bars and the adjoining flags removed progressively.

Lifting Natural Flags.

In this case it is not possible to adopt the previous method, and some other means of lifting the first flag will have to be adopted. An excellent plan is to use specially thin ratchet hooks, as described for grit setts (Fig. 43).

Concrete flagging may be laid in situ in such a way that whilst larger slabs are obtained, joints are formed to facilitate taking up, as in Fig. 90. It is advisable to use paper on the ground before laying the concrete, and also to insert paper between the joints, as these occur, to prevent adhesion.
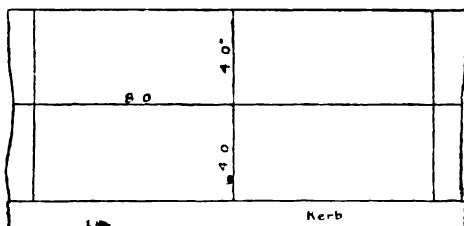
FIG. 90.—Longitudinal Straight Joints for Concrete Flagging laid in situ.

Other types of surfacing are :—

1. Tar asphalte, rock asphalte, or tar macadam.
2. Gravel.
3. Cinders, with or without chippings.
4. Red shale.
5. Tiles or bricks.

Each of these materials forms a fairly satisfactory footpath, except after frosty weather, and their adoption depends upon considerations of economy and local conditions.

Circular Turns and Crossings.

It is the usual practice to join the kerbs of two roads which are at right angles to one another by means of a circular curve.

Where this radius exceeds 15 or 20 ft. the curve will not seriously interfere with the rear wheels of vehicles. Where the radius is less than 15 ft. it is advisable to adopt a " broken " turn, i.e. a curve laid to two different radii. This should be arranged so that the sharp curve comes at the commencement of the turning and the flatter curve afterwards, according to the direction of traffic, as shown in Fig. 91. This compels all vehicles to avoid the sharp curve in such a manner that the track of the rear wheels will not grind on the flat curve. In actual practice the two circular curves may be merged so that they form one nearly elliptical.
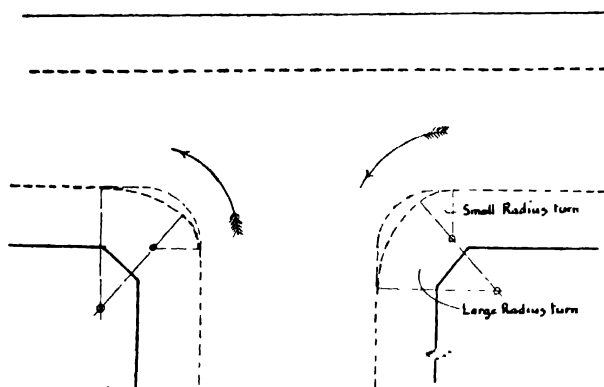
Fig. 91.—Method of arranging Circular Kerbs at Intersections to avoid Wheel-Grinding.

Crossings.

The provision of crossings for works entrances, garages, etc., necessitates the strengthening of the footpath at this point, and very often its alteration to enable vehicles to pass over it from the carriageway to the building.

The concrete crossing is perhaps the most suitable and economical type of paving to adopt. It is easily adapted to splays and curves and also for dipping into the channels and breaking the continuity of the kerb. Other forms of paving used are granite and grit setts and tar macadam, or asphalte. In many cases they are provided with kerbs to prevent vehicles from going on to the footpath. Such kerbs, however, are

undesirable from the point of view of the pedestrian, and it is much better to construct well-splayed " dished " crossings and so dispense with kerbs.

Width of Footpaths.

Various rules and formulas have been given for determining the width of the footpath in proportion to the full width of the road ; but it is unnecessary to prescribe hard-and-fast rules for this particular phase of road work. Each case must be considered on its merits, having regard to the requirements of the particular area concerned ; the following zones will require individual treatment in footpath design :—

(a) Industrial areas : medium or narrow widths.

(b) Business (or shopping) areas : wide footpaths.

(c) Residential areas : various widths and margins as desired.

(d) Rural,. unrestricted or undeveloped areas : narrow footpaths with margins.

Moreover, the character of the particular road in each area should be considered ; for instance, the completed footpath on a through or main road in a residential area will require to be wider than that of a cul-de-sac road. The use of grass or red shale margins in connection with the design of footwalks has considerable interest for the engineer. In the ideal section of the Lincoln highway (U.S.A.), 100 ft. wide, the carriageway is 40 ft. wide and the footpath—comparatively narrow—is laid along one side only, so that at any future date it can easily be widened.

CHAPTER XIV

THE problem of corrugation, or waving on road surfaces, is probably one of the most difficult and costly propositions confronting the road engineer at the present time. It is without doubt a direct result of the development of the mechanically propelled vehicle, although in a mild degree it may have occurred in the days of horse traffic by the rolling action of wheels and initially of the road roller.

The Author has given a considerable amount of time and thought to this question, and contributed a paper on the subject —which was discussed by the leading road engineers of this country at a meeting of the Institution of Civil Engineers in 1918.

Before entering into details regarding the causes and cure of corrugation it may be desirable to sum up in brief the connection between motor vehicles and the wave trouble. There are two leading factors in modern commercial traffic contributing to the destruction of roads by wave formation :—

1. *Rear-axle or rear-wheel driving.*
2. *The solid rubber tyre—in various stages of wear.*

It will be necessary to keep in view these two points in the following treatment of the subject.

The Occurrence of Corrugation.

Wave formation occurs upon almost every kind of road surface subjected to heavy motor traffic. There are one or two possible exceptions, viz. granite setts upon concrete foundation or concrete paving alone. In the case of the former, the rows of setts cannot easily become wavy, since there is only a thin sand cushion beneath and good jointing of the setts themselves. With

concrete paving the success in resisting corrugation depends upon the degree of smoothness and the rarity of cracks and joints in order to obtain an even tractive resistance to the passage of wheel traffic. As a matter of fact the consistency and the actual value of the traction has an important bearing on the beginning of wave formation. Broadly, the tendency of a surface to corrugate varies directly as the tractive resistance. The lower the tractive resistance the less chance is there of waviness being set up.

The table below (column 2) gives the results of tests carried out in 1919 by the University of California. The wagon employed was horse-drawn at 2·4 miles per hour and carried a load of 6000 lb.; the pull was registered by the compression of a calibrated spring to a dynamometer and also graphically on a strip of paper by a recording pencil. Whilst the speed of the waggon was low, the comparison is most useful. Another series of tests for tractive resistance have been carried out by measuring the petrol consumption over different types of road surface; these are shown in column 3.

VALUES OF TOTAL TRACTIVE RESISTANCE

	lbs. per 6000 lbs.	Ton-miles per gallon of petrol.
Concrete	83	30·6
Monolithic brick	—	29·7
Concrete with ⅜-in. oil top . .	143	—
Topeka (asphalte)	207	23·4
Waterbound macadam . . .	225	—
Gravel (good condition) . . .	225	21·2
Gravel (loose)	813	—
Oil macadam	258	—
Earth road	306	14·0

It must be borne in mind that the tractive resistance on the same road varies with the climatic conditions and the kind of tyre fitted to the wheels. One surface having a high traction in wet or hot weather may have a much lower value in cold, dry weather. This fact indicates that under certain conditions the chances of wave formation are very small even upon a second-

class road. Whilst the actual waviness on different road surfaces is more or less the same to the road user, the manner in which it is set up does vary considerably. Before proceeding with this part of the subject it is necessary to analyse the particular effect of back-axle driving and the features of the motor vehicle of to-day.

The driving force of the rear wheels at the road surface is tangential and horizontal only when the surface has an even and constant resistance to the movement of traffic, and in such circumstances no vibration would be set up. In practice this rarely occurs ; it may happen, for instance, at low speeds on a good average road or upon a road having concrete for foundation or surface. We may assume, however, that on the roads where
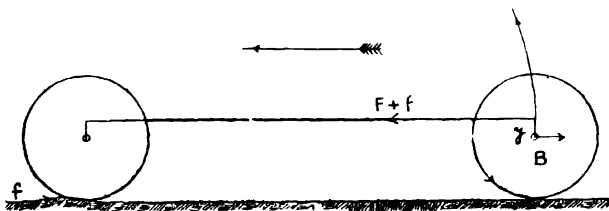
FIG. 92.—Effect of Front Wheel of Vehicle striking an obstruction.

corrugation is set up this does not occur, and that in the early development of waves there is some weakness or obstruction causing it.

Most observers will have noticed that waves sometimes form in small groups, in the vicinity of some weak spot or rigid iron cover in the road surface, and that certain portions of the road on straight lengths are practically free from waviness.

In the first instance, a study of the effect on the vehicle and the road of the front wheel striking an obstruction, as shown in Fig. 92, will explain the vibration and corrugating effect set up in the vehicle.

The driving force at wheel B is transmitted partially through the chassis in F to overcome the front-wheel resistance. A sudden increase in the latter, say, f, causes the force F also to increase, and the moment of the couple becomes $(F + f) \times y$. A vibration

is therefore set up of the rear axle about the front axle, the moment of which is fy. This vibration, harmonic in character, causes periodic wear at the driving wheels and thus produces waves.

In this particular it is of interest to note that many commercial vehicles have substituted pneumatic tyres on the front wheels though reluctant to do so on the rear wheels, so that the effect of an impact at the front is correspondingly reduced.

It is, however, in the variable resistance to the rear or driving wheels that the principal cause of corrugation will be found. It will be assumed that the driving wheel strikes an inequality, either in the form of a slight hollow or raised obstruction. Immediately the tangential force at the point of contact changes from the horizontal, as shown in Fig. 93, so that the force at the hub of the wheel which drives the vehicle is now partly horizontal and partly vertical. This can be resolved into horizontal and vertical components. The vertical component, depending as it does upon the height or slope of the hump or hollow in the road, is the force to which must be added the reaction due to spring compression, to obtain the total effect on the rear axle. The result is that there is a strong upward force acting on the rear spring and in a lesser degree on the body of the vehicle, so that the rear wheel may leave the ground—or nearly so—and permit of racing of one or both wheels until they again strike the road by the gravity of the vehicle and the reaction of the spring. The road surface has now to resist two forces, viz. an approximately vertical force due to weight and a tangential one due to driving action. The latter force has the effect of moving the fine material of the road surface towards the ridge which has just been passed over.

The shape of the waves so formed depends upon the position in the road, i.e. whether at the sides or in the centre portion of the road. Those waves in the centre are more regular in shape and often less prominent than the waves at the sides of the road, where the wheels move in one direction only. The shape of the latter is different, because the wheels strike one side of the slope only, in consequence of which the other side becomes banked up by the ground-out material.

The shape of these waves, in a case taken near the channel and on a bend, is similar to those shown in Fig. 94. The difference in the relative slopes on each side of the wave is most marked.

The peculiar wave-forming feature of the rear-wheel drive may be proved in practice by driving a motor-car over an obstruction and noticing the vibration, and then repeating the operation at the same speed but running free. The vibration experienced and its duration in the latter case is very much less than when the vehicle is under driving action.

Another point of interest is the influence of the wheel-base on back-axle-driven vehicles. It has long been observed that vehicles having a long wheel-base were much steadier than vehicles possessing a short wheel-base. The explanation of this
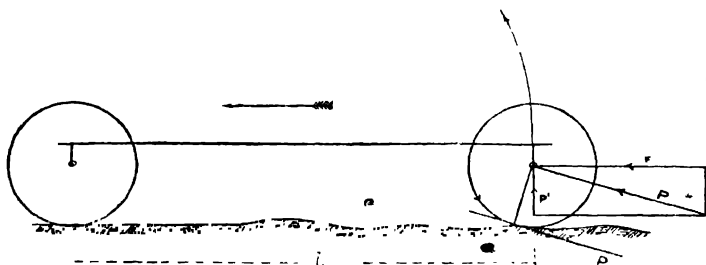
Fig. 93.—Effect of Rear Wheel of Vehicle Striking an Obstruction.

is to be found in Fig. 93, where the vertical component rotates about the front axle, the lever arm being the wheel-base, l. It would appear that the question of deflection, as in the case of a cantilever having a load at one end, enters into the case, and that the effect of the periodic upward hammering at the rear axle on the mass of the body itself varies inversely as the cube of the wheel-base (l^3). It is certain that there is a vast difference in behaviour on a bad road between a vehicle with a long wheel-base and one with a short wheel-base.

Incidentally, where there are several vehicles of the same type, and the same length of wheel-base running upon a particular road the destructive effect is infinitely greater, because each one of them vibrates in the same manner and waviness is quickly set

up. There seems to be good ground for suggesting that motor buses on a particular service should be varied in design, especially in the length of wheel-base. Standardization of this kind in motor and other similar vehicles is not to be desired.

Effect of Braking.

So far, the driving effect of vehicles only has been considered. There is a contingency, however, when the vehicle is braking and not driving ; this also has a corrugating effect on the road surface, the principal cause of which is the scraping or skidding action of the wheels at the point of contact with the road, due to the application of the brakes. The tendency of the road material to creep forward by wheel action alone is augmented by frictional force owing to braking, the effect being to create a wave which is ultimately jumped by the wheel itself and the process repeated. On a dead true and hard surface with dry-weather conditions
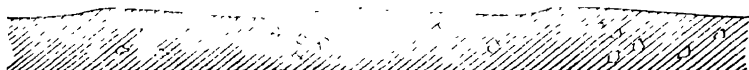
FIG. 94.—Shape of Waves on Hill Surfaces, Sides of Road, and at Crossings due to Concentrated Braking Effect.

this braking effect is reasonably smooth ; nevertheless, sudden applications of the brake cause a serious strain on any road surface and should be avoided in general. It is of interest to note the effect of the braking of motor buses at the approaches to the important crossings in London, where the corrugations are quite distinct.

Here again the shape of the waves is quite unsymmetrical, as shown in Fig. 94. The waves are flat on the one side and steep on the other. At the crossings themselves, where traffic is passing in all directions, it is almost impossible for regular waves to be formed.

It should be mentioned here that the differential gear on the modern vehicle makes it possible for one wheel to brake or skid more than the other ; this condition of things will occur when the pressure on, or braking adhesion of, the two rear wheels is unequal, as on improperly banked curves.

Corrugation on Hills.

Corrugation on hills has often been observed when it has been more or less absent on the flatter sections of the same road. There are several reasons to account for this trouble on gradients. The speeds on the up-grade are high at the bottom of the hill and the driving strain at the road surface is greater than normal ; braking action for down traffic is often a serious factor in wear of the surface. The natural effect of these forces is that the road surface is deformed or worn comparatively quickly by the excessive strains and vibrations imposed upon it by a variety of traffic. The tendency for movement is, of course, in a downward direction in every case, and waviness is quickly set up. As previously mentioned, however, it is more likely to occur at the foot or the top of the hill, or indeed at any change of direction. The Author has noticed the movement of granite setts on ballast foundation on the down-side of a heavily trafficked road, where the courses formed themselves into crescent or segmental shape by the pushing effect of the traffic. The inevitable result of movement in such cases is tilting of the setts and corrugation.

Wear at Bends.

It has been previously pointed out that without superelevation at curves an excessive wear or deformation of the road surface is bound to occur. The exact manner in which this waviness takes place is of particular interest. When a motor vehicle is rounding a bend the pressure on the outer wheels is increased and that on the inner wheels decreased. So far as the front wheels are concerned this is not very material, but in the case of the rear wheels the question of driving adhesion arises. The reduction of pressure on the inner wheel at certain speeds will permit of slipping, so that by aid of the differential gear this wheel races. A transverse vibration, due partly to the turning movement and partly to some unevenness in the road surface, is set up, and the inner wheel misses and slips the road alternately, thereby causing considerable damage and wave formation.

On the other hand, the increase of pressure on the outer wheel, together with the alternating drive due to the racing of the inner

wheel, also assists materially in the production of waves. Observations of motor vehicles passing round a curve will confirm these views. The inner driving wheel bounces readily and the smoothness of the road is quickly destroyed. One of the difficulties in this direction is that the speed of the traffic often depends upon the state of the straight sections of road, and invariably the bends are negotiated at a higher speed than would be the case if the whole length of road were wavy or a bad surface.

The trouble of waviness at bends will be partially or wholly remedied by superelevation, or by the use of concrete foundations or surface.

Causes of Skidding.

Whilst discussing the corrugation of road surfaces at bends, the real cause of skidding reveals itself. If one wheel is driving hård while the other is racing and the vehicle turning, the thrust is one-sided and not central, and the rear portion has a definite tendency to move sideways by skidding. For similar reasons a sudden application of the brakes will cause the vehicle to behave in the same way. It is sheer folly to apply brakes when the vehicle is changing direction ; the front wheel should always be steered straight when braking is done.

Skidding on wavy surfaces is always probable, and will invariably occur if the road is well cambered or when making a quick turning movement to round other traffic.

If every driver understood the fundamental reasons underlying the skidding of rear-axle-driven motor vehicles there would be fewer accidents recorded on the public highway.

Wave Formation on Waterbound Macadam Roads.

So far the construction of waterbound macadam roads has been practically omitted from the realm of modern road politics. Having regard, however, to the great mileage of road of this construction in existence and the method in which its corrugation differs from that of other classes of construction, some reference to it is desirable. The resistance to traction being relatively high some movement of the macadam surface under heavy

traffic may be expected. The weather has a more penetrating effect on a road of this class than upon any other type of road. It may be hard and frosty or damp and spongy in various degrees, each coming under the influence of the back-axle-driven vehicle. Continual dry weather causes the binding material to free itself from the macadam stone and to pass off as dust, and when this occurs the stone moves about in such a manner that the smaller stone goes to form the transverse ridges or wave crests, whilst the heavier and coarser stone remains in the hollow of the wave. It is obvious that waterbound macadam will not permit of serious movement of this kind taking place without disintegration which will render the road dangerous to traffic. Indeed, rapid corrugation and the formation of potholes in this class of road is the main reason for designating it as entirely unsuitable for modern traffic. Fig. 95 shows a typical section of a wavy waterbound macadam road.
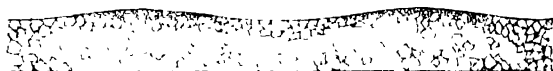

FIG. 95.—Typical Section of Wavy Waterbound Macadam Road

When the condition of the road is soft and spongy corrugation may be set up in a few hours, but it may partially smooth out again under a variety of traffic when it becomes less spongy.

The tar spraying of a waterbound macadam road will assist in preventing for a time the wave-forming tendency of traffic, as it keeps out the wet and partially resists surface movement. There is little doubt that, under certain favourable atmospheric conditions, ordinary well-constructed macadam forms a strong road material which will offer considerable resistance to the corrugating tendency of traffic.

Corrugation of Tar Macadam Roads.

The formation of waves on tar macadam roads is brought about by the fine tarred topping course moving backwards and forwards into waves whilst the base course of larger material is worn bare in the hollows. This can readily be tested by driving iron pins into the road in definite positions and at intervals

longitudinally of 18 in. to 2 ft. By this means some of the pins
will occur approximately in the hollows while the others will
occur in the waves themselves : in the former case the pin-heads
will be exposed and in the other they will be buried by the fine
tarred topping—in the case of tar-sprayed roads, the tar and
chippings—which have formed the ridges. The fact is that the
rear-axle-driven vehicle with the solid rubber-tyred wheel
pushes the tarred topping backwards and forwards into waves
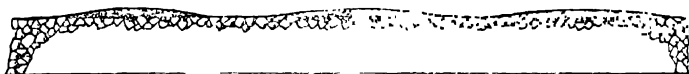at the same time that it grinds down to the lower course.

FIG. 96.—Section of Corrugated Tar Macadam Road.

The manner in which tar macadam roads become corrugated
is shown in Fig. 96.

• In the case of tar-sprayed roads it is of the utmost importance
that the chippings or sand should be applied sparingly and the
finished coat kept as thin as possible in order to produce only
shallow waves. Where periodic applications of tar and chippings
are resorted to corrugation becomes a serious matter, as there is
an accumulation of fine material, as shown in Fig. 97, which,
shaped into waves, interferes with the safe passage of traffic to
an alarming extent.

FIG. 97.—Co   ··   ′ T   ″   ′ ′ C ′pped

If traffic is concentrated in streams or lanes by reason of
limited width and a large number of vehicles, waviness may be
set up in both longitudinal and transverse directions. Especially
is this the case with an excess of fine material and warm-weather
conditions, when the concentration of wheels squeezes the
topping to the sides as well as grinding it into waves. Another
factor influencing this deformation is the creeping of the surface
material from the crown to the channel, thus causing a greater
thickness at the sides than at the crown. Naturally, therefore,

traffic may be expected. The weather has a more penetrating effect on a road of this class than upon any other type of road. It may be hard and frosty or damp and spongy in various degrees, each coming under the influence of the back-axle-driven vehicle. Continual dry weather causes the binding material to free itself from the macadam stone and to pass off as dust, and when this occurs the stone moves about in such a manner that the smaller stone goes to form the transverse ridges or wave crests, whilst the heavier and coarser stone remains in the hollow of the wave. It is obvious that waterbound macadam will not permit of serious movement of this kind taking place without disintegration which will render the road dangerous to traffic. Indeed, rapid corrugation and the formation of potholes in this class of road is the main reason for designating it as entirely unsuitable for modern traffic. Fig. 95 shows a typical section of a wavy waterbound macadam road.

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longitudinally of 18 in. to 2 ft.   By this means some of the pins will occur approximately in the hollows while the others will occur in the waves themselves : in the former case the pin-heads will be exposed and in the other they will be buried by the fine tarred topping—in the case of tar-sprayed roads, the tar and chippings—which have formed the ridges.   The fact is that the rear-axle-driven vehicle with the solid rubber-tyred wheel pushes the tarred topping backwards and forwards into waves at the same time that it grinds down to the lower course.

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• In the case of tar-sprayed roads it is of the utmost importance that the chippings or sand should be applied sparingly and the finished coat kept as thin as possible in order to produce only shallow waves.   Where periodic applications of tar and chippings are resorted to corrugation becomes a serious matter, as there is an accumulation of fine material, as shown in Fig. 97, which, shaped into waves, interferes with the safe passage of traffic to an alarming extent.

Fig. 97.—Corrugation of Tar-Sprayed and Chipped
Macadam Road.

If traffic is concentrated in streams or lanes by reason of limited width and a large number of vehicles, waviness may be set up in both longitudinal and transverse directions.   Especially is this the case with an excess of fine material and warm-weather conditions, when the concentration of wheels squeezes the topping to the sides as well as grinding it into waves.   Another factor influencing this deformation is the creeping of the surface material from the crown to the channel, thus causing a greater thickness at the sides than at the crown.   Naturally, therefore,

the waves in the middle portion of the road are likely to be less serious than those nearer the channel; longitudinal grooves are also less prominent at the crown for the same reasons.

The remedy for waviness on roads of this character suggests itself at once to the engineer who is thoroughly conversant with the cause of the trouble; i.e. to remove the corrugated fine material. Generally it will be found that the large aggregate is standing quite well and that the waves can be obliterated by scarifying and removal of the loose material. This method should not be adopted unless the waves are well developed, because there are some roads where corrugation has set in during the early life of the road and afterwards does not grow worse for some considerable time. On the other hand, if prominent waves are allowed to remain in any road the whole structure is in danger of being destroyed.

Corrugation of Bituminous Asphalte Roads.

In this connection the term of "bituminous roads" will include all kinds of bituminous asphalte work as distinct from tar macadam. As a general rule it may be said that bituminous road material is less likely to become wavy than tar macadam. This is mainly because it has greater elastic or resilient properties than those possessed by a purely tar matrix. Moreover, greater care in the mixing and uniformity of the material is observed when bitumen—which incidentally is a more expensive material than tar—is used. Bituminous macadam corrugates very much in the same manner as tar macadam by the fine medium moving into crests and the other remaining in the depressions. This movement, however, under the action of traffic is comparatively slow, as the binding power and elasticity of bitumen largely prevents it.

Influence of Road Roller.

There is a considerable body of opinion which holds that corrugation is due to initial waving with the road roller, and there is no doubt that in a great many instances initial waves are present when the rolling is finished. The Author has noticed bituminous macadam roads badly waved by incompetent rolling.

It is necessary that the greatest care and skill should be observed in carrying out rolling operations. The roller should not be a very heavy one, especially in the early stages of consolidation, although heavy rolling is recommended for clinker asphalte. Light and heavy rolling and also diagonal rolling are all useful in preventing wave formation.

The Crompton three-axle roller, designed by Colonel R. E. B. Crompton, C.B., M.Inst.C.E., is arranged to eliminate waves by means of a specially mounted centre axle which crushes down any humps formed by the other rollers. The machine is an interesting example of the attention given to this important phase of road work by an eminent engineer.

Whilst this roller cannot be praised too highly, it is generally recognized that a two-axle roller in the hands of a skilled operator will produce a reasonably smooth surface.
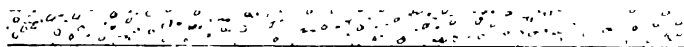
FIG. 98.—Waviness of Sheet Asphalte on Concrete Foundation.

Waviness of Sheet Asphalte.

With regard to sheet asphalte laid upon a concrete foundation the formation of waves is different from that on the other roads, as shown in Fig. 98. In this case the base course is a rigid surface which has no connection with the surface waving, and the asphalte itself is moved into transverse ridges by a process of creeping. In point of fact it is quite analogous to the rolling of a hot armour plate, which also produces waves though of a lesser frequency; and whereas armour plate is rolled between two rollers, the asphalte is only rolled on the one side, the other being more or less smooth. Iron tyres are particularly destructive in that they cause the asphalte to creep, and solid rubber tyres quickly intensify any damage done in this respect. The creeping is similar to what is supposed to occur in the rolling of macadam roads, inasmuch as the asphalte material is gradually pushed forward in front of the wheels, to mount the small ridge which is now formed. This process is repeated over the whole of the road

and the ridges become lined up, more or less, in a transverse direction. It is true that there is a limit to the depth of the waves which can be formed from a 2-in. thickness of sheet asphalte, and it is equally true that this material will hold itself together under adverse conditions. But once the wearing course becomes unsealed or perforated, water, working its way between the asphalte and the concrete, quickly affects the surrounding asphalte and shortens the life of the road.

Having regard to the low tractive resistance of the asphalte surface its corrugation is all the more remarkable. One of the contributory causes of wave formation in this class of road is the lack of uniformity in the mixture when laid, and it cannot be forgotten that any inequality in the composition of asphalte itself will produce a varying tractive resistance which in turn will cause wave-forming vibration of traffic. Unsuitable sand, a soft asphalte cement, unstable binder or mixture, too great a thickness of mixture, excessive bitumen, uneven raking, and man-hole covers may also be regarded as factors which are conducive to the formation of wavy surfaces with this kind of road surface.

This question cannot be dismissed without reference to the design of vehicles themselves, and it will be further alluded to in a later chapter.

Wave Formation on Block or Sett-Paved Roads.

At first blush, the matter of corrugation on sett-paved roads might easily be dismissed as of little consequence both to road-makers and road-users. It is a curious fact that waves are much less noticeable on a sett or wood-block paved road than upon a macadam surface, and for this reason the importance of the question as regards this class of road is not fully realized. Broadly, block paving may be classified into two distinct groups, viz.:—

1. Paving upon a non-rigid or yielding foundation, and
2. Paving upon a rigid or unyielding foundation.

In the first-mentioned group are grit or granite setts or blocks of varying sizes paved upon different foundations, such as hand pitching, ballast, or macadam; as previously pointed out, the effect of traffic upon sett paving which is capable of being

depressed is a double one, the setts being pushed bodily forward and tilted backwards. The foundation moves into waves from the movement of the setts themselves, which follow suit. The tilting of the setts, which is caused mainly by the driving wheels of motor vehicles, really accentuates the trouble, because it does not occur equally along the road. This point is illustrated in Fig. 99.

In the case of wood-block paving waviness is more liable to occur if the blocks are paved on a cushion and not on the concrete direct.

Under equal conditions small setts will corrugate more easily and with greater regularity than large setts ; the larger setts having greater depth possess greater resisting qualities to movement than the small shallow setts.

With regard to granite sett paving on a concrete foundation this is perhaps the best pavement of all for maintaining a wave-free
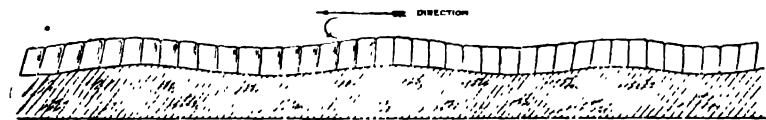
FIG. 99.—Wave Formation on Sett-paved Road on a Non-Rigid Foundation.

surface. The question of the cushion between the setts and the concrete is one of importance and is referred to elsewhere. It is desirable that the thickness of the cushion should be not more than 1 in., as with greater thicknesses and possible deterioration of the jointing material the setts would be liable to tilt and corrugate. The tractive resistance of a road of this type is low, and it appears to meet the desires of all road users and also road builders. Cube setts, 3 in. or 4 in., laid closely upon a concrete foundation, form an admirable pavement and have, of course, the advantage of being cheaper, on account of their greater covering power per ton than the deeper setts.

Corrugation on Concrete Roads.

The experience of this type of road is somewhat limited owing to its being a recent method of construction. It would appear, however, to satisfy one of the first requirements for the preven-

tion of wave trouble, in so far as it presents a smooth rigid surface, and therefore offers a low tractive resistance to traffic with an absence of vibration. It seems probable that transverse joints, unless formed obliquely, will prove to be a source of weakness and perhaps the starting-point for setting up waviness. Much will depend upon the care with which the concrete is laid and upon other factors which will be alluded to later.

It is somewhat difficult to write generally upon the subject of corrugation, and further methods of alleviating it are referred to in several of the other chapters of this volume ; the influence of tyre equipment, for example, is a most potent factor, and it is desirable for the road engineer to give almost as much attention to this feature of vehicle design as to the production of a perfect road surface.

CHAPTER XV

MEASUREMENT OF WEAR

THE measurement of wear of road surfaces is necessary in order to estimate from time to time the suitability of the paving and the probable life of the road. With regard to block pavements the amount of wear may generally be observed with the eye, without recording profiles or periodically measuring or weighing particular blocks. In the case of the macadam or other type of road—with the exception of concrete—built upon a non-rigid foundation, the difficulty is to estimate what proportion of the wear recorded by the instrument is due to a settlement of the road, and not to legitimate wear from traffic ; this point has also to be considered in connection with bituminous roads, even when laid upon reinforced concrete, as this material permits a certain amount of compression in itself without a relative loss due to wear.

Usually measurement of wear consists of taking cross-sections at certain definite points along the road with reference to heights or bench-marks at the side of the road. Wire is strained across at a given tension from standards fixed in cast-iron sockets on either side of the road. This method does not go far enough, since it does not show the waviness of the surface. In point of fact, it is not improbable that the cross-section may show an elevation or raising of the surface, owing to its occurrence at the crest of a wave ; on the other hand, it may show a depression, if it happened to occur at the hollow of a wave. It is necessary, therefore, in order to examine fully the wear of the road, to take longitudinal sections as well as cross-sections.

The tracing of the longitudinal section may be carried out by using a portable 18-ft. straight-edge as adopted by the Road Board some years ago (Fig. 100), or a simpler form of this

instrument which the Author has designed, as shown in Fig. 101. It consists of a wooden straight-edge 12 ft. long by 4 by 1 in. strengthened by a light angle-iron to prevent twisting, and a chart fixed to the side of it. A special horizontal slider containing a vertical slider and pencil runs on a wheel along the bottom of the straight-edge, and the slope of the wave is recorded exactly on the graph. For subsequent records at the same point the straight-edge should be set to the same position by reference to
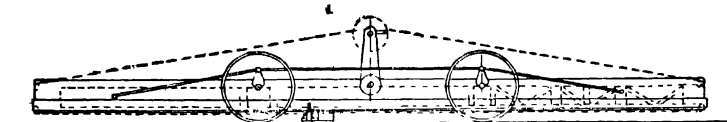
FIG. 100.—Road Board " Pen Carriage " for Measuring Wear.

the fixed bench-marks so that the road surface is again traced on the same graph, thus showing the movement of the wave or the development of the wave crests.

With regard to cross-sections, these will indicate the variation in wear between crown and channel. A complete record of this variation will be obtained if 2 or 3 cross-sections are taken close together, say, at 1-ft. intervals, so that at least one crest and one hollow will occur approximately on these sections. Moreover, the instrument may be used longitudinally
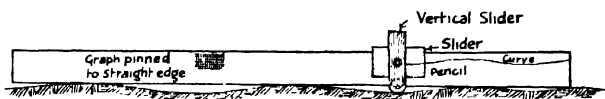
FIG. 101.—Simple Form of Straight-Edge for Measuring Waves.

over the particular section of road to complete the examination of wear.

Measurement of Wear on Concrete Roads.

Measurement of the wear of the concrete road is perhaps of more importance than that of any other type of road, as the reduction in thickness represents a more serious reduction in strength, having regard to the fact that the strength varies approximately as the square of the thickness.

The concrete road being as yet somewhat in its infancy, very little is known as to the rate of wear of the different aggregates beyond the fact that it does vary, and there is considerable scope for research in this direction. The apparatus used by the Bureau of Public Roads consists essentially of a fine wire stretched tightly across the road at a constant height, together with an inside micrometer for measuring the distance from the road surface to the wire, as shown in Fig. 101A. The wire is stretched at a tension between two blocks at either side of the road, which are provided with adjustable screws and a rod resting on the flat tops of a bronze plug at a depth of $\frac{3}{4}$ in. below the level of the surface. An electric buzzer is mounted on the side of the blocks, and a micrometer which measures the depth below the wire at 1-ft. intervals is provided with a flexible wire so that the circuit is completed as soon as contact is made. The buzzer indicates
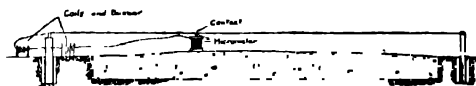
FIG. 101A.—U.S.A. Apparatus for Measuring Wear of Concrete Roads.

this completion of the circuit. The instrument registers to the nearest 0·001 in. if required.

In view of the fact that the concrete road is probably less subject to waviness than any other type of road, cross-sectional measurements may be of greater value than longitudinal measurements.

Tests to Determine the Wearing Qualities of Aggregate

French Coefficient of Wear.

The determination of the wearing qualities of aggregate is performed by means of the Deval abrasion machine. This consists of 1 or 2 iron cylinders mounted on a horizontal shaft so that the axes of the cylinders make an angle of 30° with the shaft, as shown in Fig. 102. The aggregate is thrown from one end to the other, which action tends, by abrasion and impact, to break it into fine particles. The machine revolves at a rate of 30 to 33 revolutions per min. for 10,000 turns, and the worn

material which will pass a $\frac{1}{16}$-in. mesh is considered the amount of wear.

Then the French coefficient of wear $= \dfrac{400}{W}$ where $W = $ weight in grams of the detritus under $\frac{1}{16}$-in. size per kilogram of rock used.

A good wearing rock should give a coefficient of about 20, which value has been adopted as a standard by French engineers. Above 20, therefore, the wearing quality is very high, and below 10 it is low.
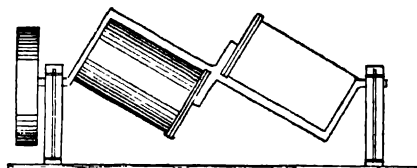
FIG. 102.— Deval Abrasion Machine.

Attrition Test.

This test is made in the 4-cylinder Deval type machine. 11 lb. (5 kg.) of rock, numbering as nearly 50 pieces as possible, are placed in a cylinder, and the machine revolved 10,000 times at a rate of about 30 per min. In the wet test 1·1 gal. (5 litres) of water is placed in the cylinder with the 11 lb. of stone. The percentage of loss is estimated from the amount of material removed which will pass through a sieve of $\frac{1}{16}$-in. mesh.

Resistance to Abrasion.

The tests are made in an abrasion (or hardness) machine of the Dorry type. The specimen is prepared in the form of a cylinder 1 in. diameter, 1 in. long. This is held in contact with the rim of a rotating cast-steel disc under a pressure of 3·5 lb. per sq. in. (250 grams per sq. cm.). Crushed quartzite, to act as abrasive, is fed continuously upon the surface of the disc. The loss of weight of the specimen is determined after 1000 revolutions of the disc at about 28 revolutions per min.

Repeated Blow Impact Tests.

These tests are made in a Page impact machine. The specimen is prepared in the form of a cylinder, 1 in. diam., 1 in. long. The hammer of the testing machine weighs 4·4 lb. (2 kg.). The test consists of a 0·4-in. (1 cm.) fall of the hammer for the first blow and an increased fall of 0·4 in. (1 cm.) for each succeeding blow until failure of the specimen occurs. The number of blows required to cause failure is taken to represent the toughness of the rock.

Cementation Value of Rock.

For the purposes of the tests, the rock is ground up with water in the standard Ball mill, and from the resulting paste six briquettes are formed under a pressure of 1880 lb. per sq. in. (132 kg. per sq. cm.). These briquettes are dried for 24 hours and then tested under repeated impact in a Page impact machine, and the number of blows necessary to destroy the resilience of the briquette is determined. This number is taken to be the cementing value of the material.

Tests for Absorption.

These tests are made by drying the sample until it is of constant weight, and then immersing it in water and weighing immediately after immersion, and also after immersion for four days.

New Ways of Testing Aggregate.

A new field of investigation is promised by the employment of the Röntgen ray and the use of microphotography in the testing of concrete. Experiments by microphotography consist in enlarging by special apparatus, with the aid of the microscope, samples which are observed by means of transmitted or reflected light. In the latter case, the surface of the object is illuminated by a 1250 c.p. Osram-azo-projection lamp, carried on a double swivel and mounted so as to be directed to any required angle. The microphotographs indicate clearly the presence of pores or bubbles in defective concrete and also the process of rust formation.

The Röntgen ray has been used upon samples of reinforced concrete to detect the presence of rust and the influence of rust-forming ingredients. It is necessary that the condition of the iron, at the time of placing in the concrete, should be known in order to follow the changes taking place in the mass by observations at regular intervals. These experiments indicate that the permeability of the concrete to the rays decreases with the increase of the proportion of the cement used.
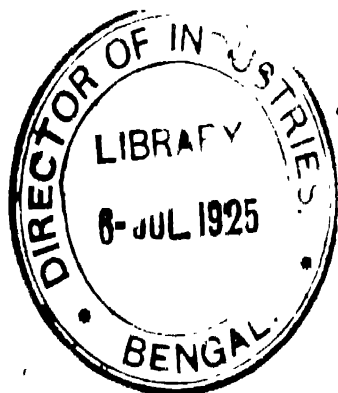
CHAPTER XVI

THE question of tyre equipment hitherto has been greatly neglected, and prior to the War the iron tyre for the commercial vehicle was the rule rather than the exception. The damage done by iron-tyred lorries is somewhat difficult to estimate, but the provision of a speed limit of 5 m.p.h. has had the effect of minimizing the damage. At low speed the vibration of a vehicle is sensibly different from the vibration at higher speeds, and therefore the iron tyre need not be considered as the main destructive force on the road. From the owners' point of view the solid rubber tyre has a considerable advantage over the iron tyre, inasmuch as the higher speeds permitted enable such a vehicle to effect a much higher ton-mileage per day than the slow-speed vehicles, and the solid rubber tyre has become popular mainly for this reason.

The destructive effect of the solid-tyred vehicle on the road surface has already been referred to as being a contributory factor in causing corrugation. The damage, however, varies according to the amount of wear that the tyre has undergone. The fact that there is no limit fixed for the amount of wear of a solid tyre is one of those curious anomalies which have occurred from time to time in the history of road transport. The amount of rubber may be worn almost to the steel base, or the tyre may have a piece torn away without the law requiring any reduction of speed. Moreover, the rubber itself may have ceased to be resilient and the cumulative effect upon the road is exceedingly destructive. In any case, the cushioning properties of the solid rubber are reduced considerably under weight as the density of the rubber is increased.

It is clear, therefore, that there is urgent need for further legislation to embody regulations which will define limits to prevent damage from these causes in the interests of road economy.

At the same time the substitution of the pneumatic tyre cannot be too strongly urged. In this connection it should be stated that there are many owners who now realize that these tyres are commercially an economical proposition, and consequently are converting their vehicles to take them.

Unsprung Weight.

The unsprung weight of an iron- or solid rubber-tyred vehicle may be defined as that part which is interposed between the main springs and the road. The amount of this weight and its ratio to the total weight of the vehicle is a varying quantity. It depends upon the following conditions :—

1. The type of vehicle.
2. The kind of tyres—whether solid rubber or iron.
3. The position of the load relative to the axles.
4. Whether the vehicle is loaded or unloaded.

The types of vehicle on the road at the present time are so numerous that it is impossible to enter into details with regard to them. With regard to the tyres the iron-shod wheels show no reduction of unsprung weight, whereas the solid rubber does effect some lessening of the weight which depends, of course, on the amount of wear on the tyre. The position of the load affects the axle weights and this influences the reserve of resiliency in the tyre itself, and also it may increase the unsprung weight by flattening the mainsprings until they are almost out of action. If the vehicle is unloaded, it is possible that the springs are insufficiently sensitive to render the body " sprung," with the result that this is added to the weight below the spring. It has often been stated that there is more damage done to a road surface by unloaded vehicles than by loaded vehicles. This is because unloaded vehicles have a greater ratio of " unsprung weight " and their average speeds are greater.

One is led, therefore, to the conclusion that the ideal arrange-

ment of springing is to have some form of cushion at the wheel contacts which would act for the whole vehicle. Various devices for sprung wheels have been placed on the market, but none of these can equal the pneumatic tyre for efficiency. The pneumatic tyre is an air cushion the general adoption of which would save millions of pounds in road construction annually.

Impact

The Bureau of Public Roads, Washington, has carried out a series of valuable experiments, extending over a period of two years, on impact with various types of vehicles, tyres, and loads. The results obtained will no doubt influence the U.S. authorities in the near future on the question of license fees. The joint committee representing road engineers and vehicle interests was appointed in 1920 with a view to making recommendations on taxation which would secure uniformity in the forty-eight States. At that time the license fees were different in almost every State ; in some cases they did not cover the cost of road repairs, and in others they were much in excess. One of the findings of this committee was that a sliding scale in favour of pneumatic tyres should be adopted in the interest both of the owner and of the road authorities. This committee realized that the design and equipment of motor vehicles can be largely influenced by the taxation authorities.

In view of the importance of the American impact tests the Author proposes to give a full description of them and a summary of the conclusions drawn from the results.

Two methods of measuring impact were devised as follows :—

(a) By deformation of copper cylinders ½ in. diam. and in length, placed in the bottom of a heavy cylinder under a neatly fitting plunger which receives the impact from the wheel. The deformation is measured with a micrometer and compared with the deformation produced by static forces. Unfortunately the cylinder acts to some extent as a cushion, and only the average force of impact is measured ; the maximum impact, therefore, is approximately twice the average.

(b) By the autographic method. This consists of a paper tape, moved at right angles to the pencil movement at a known uniform

speed. The pencil is operated by the vertical movement of the mass of the vehicle as it travels; thus a space-time curve is produced and the second derivative of this curve will give the acceleration at any given point. This method was adopted later than the copper cylinder method, and has therefore not been used to any great extent.

A special runway of concrete was constructed for the purpose of making the tests; it was designed so that the head of the plunger was flush with the road surface. The obstruction tests were made at this place by bolting to the plunger-head a strip of
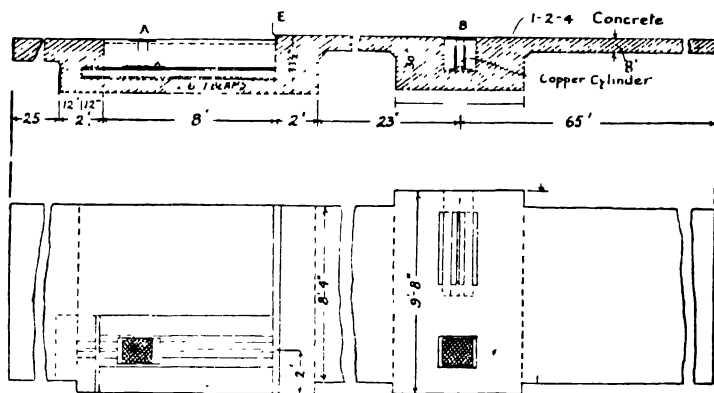
FIG. 103.—Section showing Special Concrete Road Construction and Apparatus for Impact Tests (U.S.A.).

hardwood 4 in. wide and 16 in. long, using thicknesses of $\frac{1}{4}$ in., $\frac{1}{2}$ in., 1 in., 2 in., 3 in., and in the case of pneumatic tyres, 4 in.

The " drop " tests were made at the drop-off edge E, Fig. 103, the plunger beyond and in the lower pit being so placed that the plunger-head A may be elevated to give " drop " distances varying from 0 to 3 in. The plunger could also be moved away from the edge E any distance to receive the blow of the wheel as it jumped various distances depending upon the speed of the truck. The $\frac{1}{2}$-in. copper cylinder, previously mentioned, was placed under each plunger in order to secure data from both types of tests during one passage of the truck.

The impact of only the left rear wheel was measured. A

bridge was placed over each plunger-head to protect it from the front wheel. As this wheel passed, the bridge was jerked out, leaving the plunger-head clear to receive the impact of the rear wheel. In the obstruction test the right wheels (front and rear) did not strike the obstruction, but in the drop test both right and left wheels were caused to drop the same amount. The speeds were determined over a distance of 30 ft. by timing with a stop-watch.

The use of copper cylinders reduces the impact value, and a few experiments were conducted to determine approximately the cushioning effect. Copper cylinders of different diameters were subjected to the impact of a constant weight, falling the same height in each case, this being repeated by changing the height of fall.

Autographic space-time curves of these same impacts without using a copper cylinder were also taken. The intermediate sizes of the copper cylinders were used to obtain an idea of the progressive variation due to different cushioning effects. Thus for values of 1 in. drop the $\frac{1}{2}$-in. copper cylinder indications should be increased 42 per cent. These corrections were applied for different heights of drop in order to obtain more values of the impact force.

The impact values are the actual static indications from the $\frac{1}{2}$-in. copper cylinder as measured immediately after the test, and are known as the static equivalent. To arrive at the maximum force value these static equivalents are corrected by increasing each by the cushioning factor and multiplying by some factor to allow for the fact that the cylinder measures the average impact and not the maximum. The latter factor may equal from 1·5 to 2, depending upon the equation of the stress-strain diagram.

It should be pointed out, however, that no high degree of accuracy was attempted in the experiments, a 5 to 10 per cent variation being considered unimportant.

The speed of the truck is regarded as one of the most important factors and one which is subject to more traffic rules than any other. The speed values, therefore, in miles per hour, have been made the independent variable in most of the tests.

Trucks or lorries of different weights and capacities have been

used in the tests. A tabulation of the weights and equipments of some of the tricks used is shown below.

Some of the trucks have comparatively heavy unsprung parts, and others have light unsprung parts. The effect of this factor was especially studied in the tests upon two trucks of the same
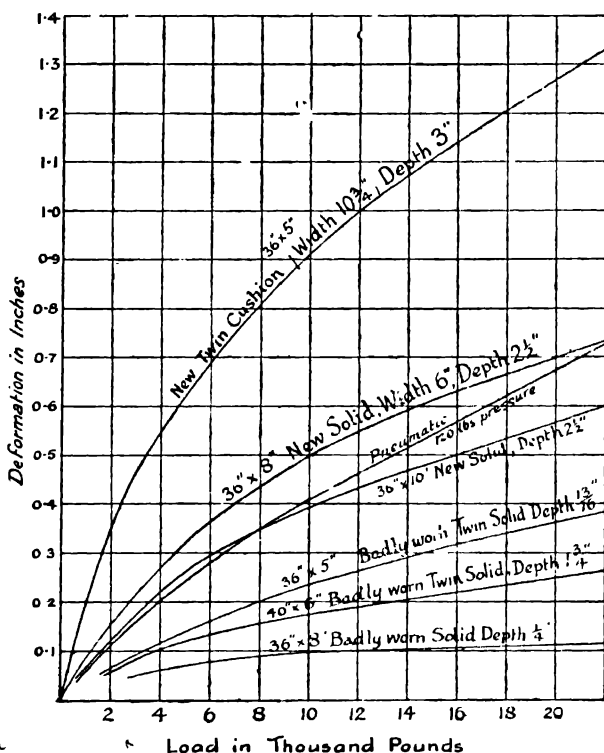
FIG. 103A.—Graph showing Deformation of Various Kinds and Conditions of Tyres under Variable Loading.

capacity under different loading and speed, each truck being equipped with the same set of tyres.

As far as possible each truck was tested at different speeds and loadings with several kinds and conditions of tyres. The height of the obstruction or irregularity was made one of the variables in most of the tests.

The experimental results obtained have been plotted on no

TABLES SHOWING SIZE, WEIGHTS, AND LOADING OF TRUCKS

Truck	Rated capacity	Empty weight Total	Empty weight Front	Empty weight Rear	Unsprung weight Two rear	Unsprung weight One rear	Distribution of load Total	Distribution Front axle	Distribution Rear axle	% load on rear axle	Total sprung weight on one rear wheel cargo truck	Spring deflection for total sprung weight	Total load on road from one rear wheel
	Tons	Pounds	Pounds	Pounds	Pounds	Pounds	Tons (2,000 lbs.)	Pounds	Pounds		Pounds		Pounds
W	1¼	6,320	2,250	4,050	2,030	1,066	0	0	0	0	970	—	2,035
	"	"	"	"	"	"	1¼	200	2,880	90	2,410	—	3,475
	"	"	"	"	"	"	2¼	28	4,410	98	3,175	—	4,204
A	2	7,800	3,300	4,500	2,000	1,000	0	0	0	0	1,250	1·02	2,250
	"	"	"	"	"	"	2	100	4,100	120·5	3,300	2·70	4,300
	"	"	"	"	"	"	3	400	5,600	93·5	3,900	3·19	4,900
A	5	9,860	3,900	5,950	3,900	1,950	0	0	0	0	1,050	·38	3,000
	"	"	"	"	"	"	5	50	9,950	100	5,950	2·12	7,900
	"	"	"	"	"	"	7½		15,150	100	8,650	3·09	10,800
P	3-3½	9,500	3,800	5,700	3,400	1,700	0	0	0	0	1,150	·48	2,850
	"	"	"	"	"	"	2½	400	4,600	92	3,450	1·44	5,150
	"	"	"	"	"	"	4½	700	8,300	92	5,300	2·25	7,000
B	3	11,370	4,620	6,850	3,675	1,837	0	0	0	0	1,588	·74	3,425
	"	"	"	"	"	"	3·6	580	6,620	92	4,900	2·62	6,735
	"	"	"	"	"	"	5	980	9,020	92	6,100	3·63	7,935
Ka	5½	11,800	5,300	6,500	2,000	1,000	0	0	0	0	2,250	1·12	3,250
	"	"	"	"	"	"	5	540	9,620	95	7,060	3·73	8,060
	"	"	"	"	"	"	7½	900	14,650	94	9,575	5·12	10,575
Kc	7½	13,600	5,240	8,380	3,000	1,500	0	0	0	0	2,695	1·08	4,195
	"	"	"	"	"	"	3½	310	6,940	104	6,200	2·70	7,700
	"	"	"	"	"	"	8½	380	16,720	97·5	11,000	4·78	12,500
Ks	5	13,600	5,860	7,740	2,260	1,130	0	0	0	0	2,740	—	3,870
	"	"	"	"	"	"	6·4	1,050	10,680	92	8,080	—	9,215
	"	"	"	"	"	"	7·15	1,020	13,280	93	9,380	—	10,510
KC	6½	9,800	4,900	4,900	2,600	1,300	0	0	0		1,600	·53	2,900
	"	"	"	"	"	"	5	650	9,350	93·5	5,800	1·93	7,100
	"	"	"	"	"	"	7½	650	14,350	95·6	8,800	2·93	10,100
G	5	12,700	—	—	3,000	1,500	5	—	—	—	7,080	1·75	9,480
					3,000	1,500	7½	—	—	—	10,280	2·62	11,775

fewer than 133 charts, some of which are reproduced herewith
(Figs. 103A–106).   In several cases during the test it was noted
that certain oscillations set up by the front wheel striking the
obstruction were sufficient to materially change the impact of
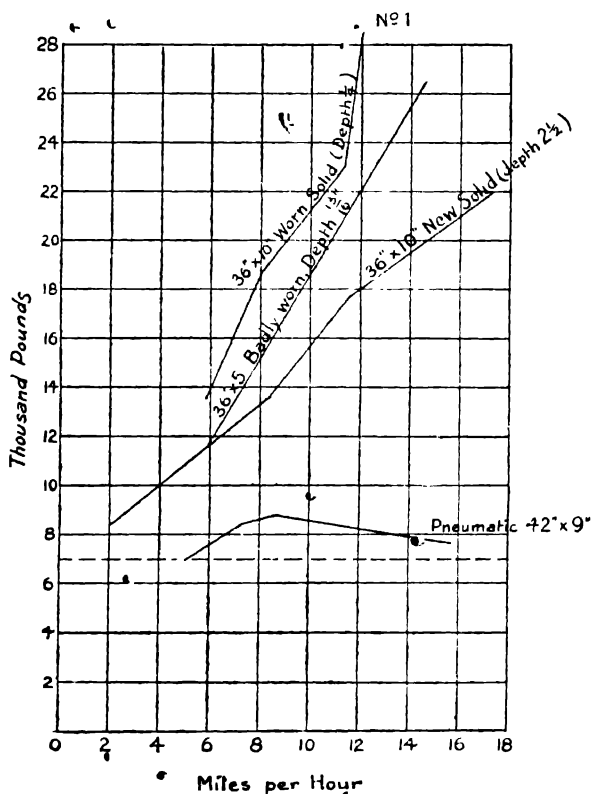the rear wheel.   Fig. 103A shows the deformation of various kinds

FIG. 104.—Comparison of Tyre Equipment of 3½-ton Truck,
relative to Speed.

and conditions of tyres employed relative to load, and indicates
clearly the high elastic value of the cushion tyre and the low
value of worn solid tyres.

In the obstruction tests a considerable change is shown in the
impact value, but only a slight change in tyre deflection.   The
impact value is greater for solid rubber tyres and less for the

pneumatic tyre : at a speed of $17\frac{1}{2}$ m.p.h. the pneumatic tyre gives an impact value of only 1·75 times the rear-wheel pressure on the road surface, the cushion tyre over three times, and the solids 4·3 to 5·1 times. The cushion tyre gives an impact value of 63 per cent of the solid tyre average and the pneumatic only
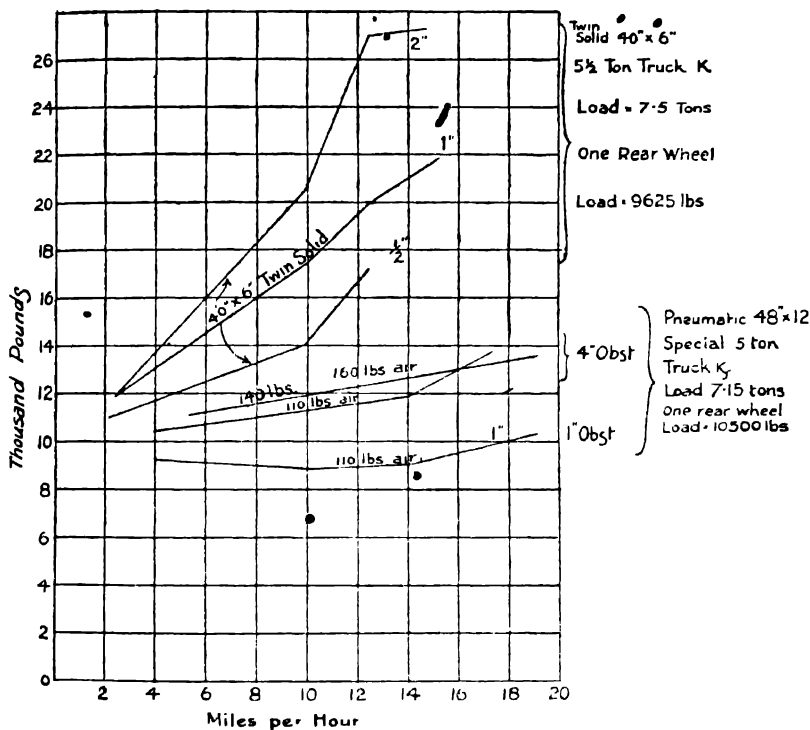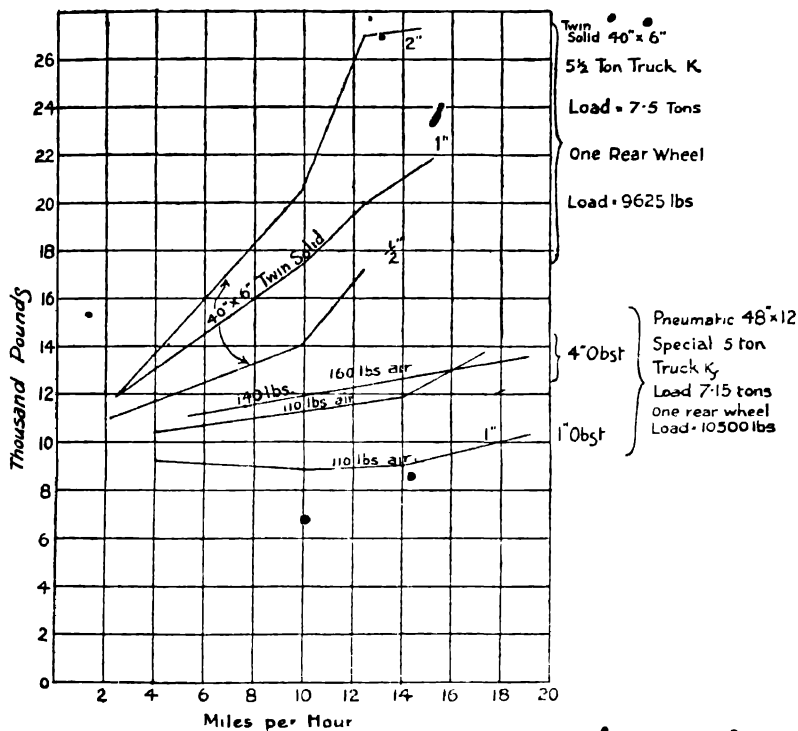
Fig. 105.—Comparison of Solid and Pneumatic Tyres with similar Trucks.

36 per cent. It will be observed that the impact value for the pneumatic tyre increases only very slightly with the increase of speed.

Another comparison of tyre equipment, but for a $3\frac{1}{2}$-ton truck carrying a $4\frac{1}{2}$-ton load, is shown in Fig. 104. The total load on one rear wheel was 7000 lb. and the unsprung weight was 1300 lb.: the pneumatic tyre equipment showed an impact force of only

fewer than 133 charts, some of which are reproduced herewith
(Figs. 103A–106). In several cases during the test it was noted
that certain oscillations set up by the front wheel striking the
obstruction were sufficient to materially change the impact of
the rear wheel. Fig. 103A shows the deformation of various kinds

FIG. 104.—Comparison of Tyre Equipment of 3½-ton Truck,
relative to Speed.

and conditions of tyres employed relative to load, and indicates
clearly the high elastic value of the cushion tyre and the low
value of worn solid tyres.

In the obstruction tests a considerable change is shown in the
impact value, but only a slight change in tyre deflection. The
impact value is greater for solid rubber tyres and less for the

pneumatic tyre : at a speed of 17½ m.p.h. the pneumatic tyre gives an impact-value of only 1·75 times the rear-wheel pressure on the road surface, the cushion tyre over three times, and the solids 4·3 to 5·1 times. The cushion tyre gives an impact value of 63 per cent of the solid tyre average and the pneumatic only

Fig. 105.—Comparison of Solid and Pneumatic Tyres with similar Trucks.

36 per cent. It will be observed that the impact value for the pneumatic tyre increases only very slightly with the increase of speed.

Another comparison of tyre equipment, but for a 3½-ton truck carrying a 4½-ton load, is shown in Fig. 104. The total load on one rear wheel was 7000 lb. and the unsprung weight was 1300 lb.: the pneumatic tyre equipment showed an impact force of only

15 per cent more than the actual wheel load. Tyre No. 1, which was much worn, gave very high impact values at 12 m.p.h. ; the thickness of rubber was only ¼ in: above the rim. The impact values from the other solid tyres were somewhat in proportion to their deflection or condition.

In Fig. 105 is also a comparison between the effects of solid
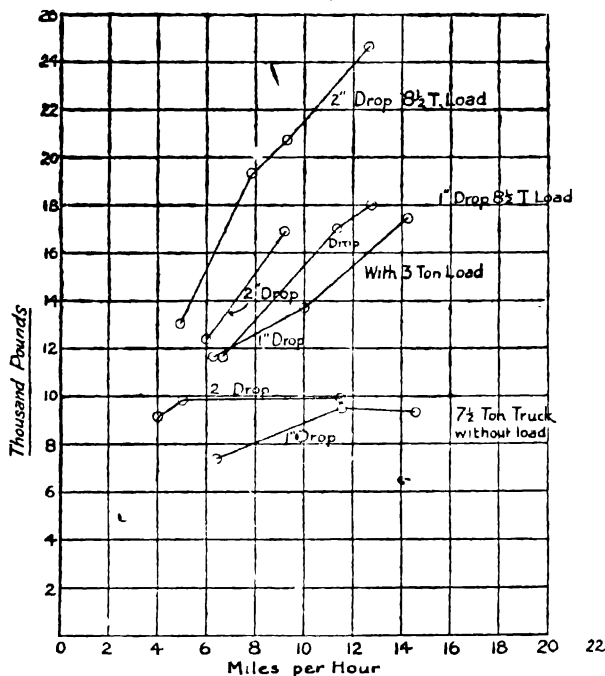
Fig. 106.—Comparison of Trucks of different capacities ;
Impact vs. Speed.

and pneumatic tyres for a 5- and a 5½-ton truck loaded with 7 and 7½ tons respectively. It will be seen that in the case of a 4-in. obstruction with pneumatic tyres the resulting impact was very much less than when using a solid tyre on ½-in., 1-in., or 2-in. obstruction. Another point of interest here is the effect of air pressure in the pneumatic tyres on the value of impact force.

A comparison between two 3½-ton trucks having the same

weight upon the rear wheels in each case but with unsprung weights of 1950 lb. and 1300 lb. respectively, both trucks having similar tyres, showed very clearly that the truck with the lower unsprung weight produced a much lower impact value than the other one.

Another comparison of interest is that showing the relative values for trucks of different capacities (Fig. 106). This shows that a light truck has a high impact value at high speeds, and that in many cases this is higher than a heavier truck running at a lower speed, although the latter produces a continuous heavy pressure on the road in addition to the impact.

General Conclusions from U.S.A. Tests.

The exhaustive character of the above tests enables one to draw many conclusions concerning the damage done to the road surface by the various types of vehicles and tyres. In the first instance the pneumatic tyre is shown to be practically non-injurious at any speed. Secondly, solid rubber tyres should have a high rate of tyre deflection to produce the lowest impact, and worn tyres should not be tolerated; and lastly, the unsprung weight should be as low as possible. These points will be dealt with in order.

Pneumatic Tyres and their relation to Road Users.

The results of the tests of the Bureau of Public Roads relating to the pneumatic tyre bring into prominence the fact that this type of equipment will do more to save the roads from wear and heavy maintenance charges than any reform in road engineering practice. In treating of the question of road corrugation the Author was firmly convinced that the contribution of the pneumatic tyre towards wave formation was practically negligible. The main reason for this is that the air cushion provides a perfect springing at the point of road contact and the effect of unsprung weight is reduced to vanishing-point: also, the cushioning properties are retained at the end of a blow. So far as rear-axle driving is concerned, the pneumatic tyre goes a long way to preventing wave repetition and reducing the effect of the blow from the rear wheels on the slope of waves already formed. There is little doubt that the solid-tyred vehicle is doing almost all the

damage to the road surface, and that the pneumatic-tyred vehicle only takes part in the unpleasantness of passing over the bad surfaces without perhaps making them appreciably worse. The dimensions and pressure of air in these tyres are matters of considerable importance. 'A large section of oversize of tyre will give better results than a small tyre, as it is equivalent to softening the leaf springs of the vehicle and the increased cushioning effect is most pronounced.

Another advantage claimed for oversize of pneumatic tyres is an increased mileage for a given quantity of fuel. There is undoubtedly some truth in this contention, and it follows naturally that the wear on the road surface is reduced proportionately.

With regard to the air pressure in the tyre itself, this is a matter of finding a mean value which will afford reasonable comfort and at the same time obtain the maximum wear from the tyre. A low air pressure gives the greatest cushioning effect and does a minimum amount of damage to the road surface, but it is not good for the life of the tyre, and moreover the vehicle is not safe on the road under such conditions. Many accidents have occurred through the bursting or skidding of soft tyres, and the safer method is to have the tyres fairly hard. The correct air pressure can be determined very readily by the use of a pocket pressure gauge applied to the valve of the inner tube.

The following table indicates the loads and pressures for different sizes of tyres :—

TABLE OF LOADS AND INFLATION PRESSURES

Section of Tyre.	Dun. B.E. Max. Tyre Load	At Pressure of	Dun. Cord B.E. Max. Tyre Load.	At Pressure of	Dun. Cord S.S. Max. Tyre Load.	At Pressure of
65 mm. or 2½″	300 lb.	40 lb.	350 lb.	35 lb.	—lb.	—lb.
80 mm. or 3″	375 ,,	45 ,,	400 ,,	40 ,,	—	—
85 mm.	465 ,,	50 ,,	— —		—	—
90 mm. or 3½″	520 ,,	55 ,,	600 ,,	50 ,,	600 ,,	50 ,,
100 mm.	685 ,,	60 ,,	—		—	—
105 mm. or 4″	815 ,,	65 ,,	850 ,,	60 ,,	850 ,,	60 ,,
120 mm. or 4½″	1100 ,,	75 ,,	1200 ,,	70 ,,	1200 ,,	70 ,,
135 mm. or 5″	1500 ,,	85 ,,	1700 ,,	80 ,,	1700 ,,	80 ,,
150 mm.	1700 ,,	85 ,,	—		—	

The loads given are maximum loads per tyre for the pressures shown. Double the tyre load to get axle load. For the exceptional cases some adjustment of the above schedule of loads and pressures may be necessary. This can be arranged by increasing or decreasing the air pressure as the load may be greater or less than the figures given. Such variations can, of course, only be made within limits, such as may be covered by air pressure variations of 5 or 10 lb., or in extreme cases of 15 lb., greater or less than the schedule pressure.

The following table shows the increase or decrease in loads for each increase or decrease of 5 lb. of air pressure.

Section of Tyre.	Variation of loads per tyre permissible per 5 lb. increase or decrease of inflation pressure.	Section of Tyre.	Variation of loads per tyre permissible per 5 lb. increase or decrease of inflation pressure.
65 mm. or 2½″	35 lb.	105 mm. or 4″	60 lb.
80 mm. or 3″	40 ,,	120 mm. or 4½″	75 ,,
85 mm.	45 ,,	135 mm. or 5″	100 ,,
90 mm. or 3½″	50 ,,	150 mm.	100 ,,
100 mm.	55 ,,		

The substitution of pneumatic tyres on the front wheels of commercial vehicles is a step in the right direction. It is generally understood that the air cushioning increases the life of the engine and contingent parts by reducing vibration. It does more than this ; it prevents almost entirely the rear-axle vibration which is set up when the front wheels strike an obstruction or pothole. Of course, there are objections to pneumatic tyres on the heavier commercial vehicles ; they require frequent attention, and there is always a possibility of a burst occurring and causing loss of steering control and delay in repairing or renewing the tyre in order to resume the journey.

Comparison of Pressure Intensities of Pneumatic and Solid Tyres on Road Surfaces

A further comparison of the effect of pneumatic and solid tyres on road surfaces is available by reference to the diagram shown in Fig. 107, which represents the tyres used in certain experiments carried out in 1922 at Messrs. Michelin's works in France. In the

case of the twin solid tyres, the area of contact with the road, when under load, is shown by the shaded area equal to 16·12 sq. in. for each tyre ; this area is by no means under an equal intensity of pressure—assuming, of course, smooth rolling conditions—and at points marked (a) the pressure will be practically zero. The maximum intensity of pressure will occur at (b), i.e. in the centre of the area, and from this point it will decrease to a greater or less extent in different directions towards the edge.
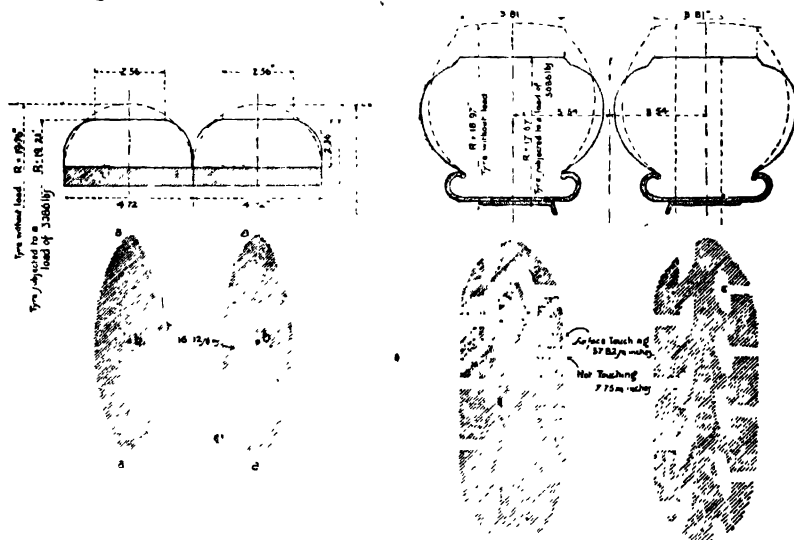
FIG. 107.—Relative Areas of Contact with Solid and Pneumatic Tyres.

An important point in this connection is that the elastic property of the rubber is very much diminished when under pressure ; consequently where the pressure is greatest the modulus of elasticity of the rubber is least.

The pneumatic tyre presents an entirely different point of view ; the area of contact of one tyre under similar loading W is 37·82 in., and the area covered but not touching owing to non-skid marks is 7·75 sq. in. In this case the intensity of pressure over the shaded area is practically uniform, since this is trans-mitted and distributed by the air pressure itself.

Assuming a maximum intensity of pressure, P, in the solid tyre equal to twice the average, the value becomes $P = \dfrac{2W}{16 \cdot 12}$ and for the pneumatic tyre $P = \dfrac{W}{37 \cdot 8}$; roughly a proportion of $4\frac{1}{2}$ to 1.

It is not difficult, therefore, to realize the great benefit to road surfaces obtained by the use of pneumatic in place of solid tyres.

Cushion and other Tyres.

There is considerable scope for improvements in the design of solid rubber tyres, and already many valuable sections of tyre
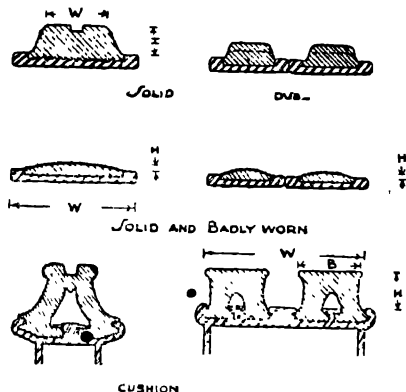
FIG. 108.—Sections of Solid and Cushion Tyres.

are on the market. The cushion tyre shown in Fig. 108 represents a very great improvement on the ordinary plain section of tyre ; the U.S.A. impact tests demonstrate plainly that the cushion tyre is very much less destructive on the road. A wide solid tyre does not improve matters very much, since on a well-cambered surface the whole of the tread is not properly in contact with the road, and the pressure on the portion of the road which is in contact is intensified thereby. Sections of new and worn solid tyres are also shown in Fig. 108.

Depth of Rubber is far more Important than Width.

Other experiments on cushioned tyres in the direction of a combined solid and pneumatic tyre have been carried out with

varying success, and there is every reason to hope that this kind of rubber tyre, at least, will quickly supersede the plain solid tyre.

Steel tyres on motor lorries are uneconomical in the commercial sense and have practically disappeared from the public highway. Recent traffic returns indicate that on busy main roads carrying heavy industrial traffic there are no steel-tyred motor vehicles shown on a count of a 16-hour day.

The Springing of Vehicles.

This feature of design of motor vehicles is one which in the past has received very little attention from the road engineer, with the result that road surfaces have been damaged unnecessarily. The arrangement of springs to suit all conditions of loading, speed, and road surface is almost an impossibility ; there are, however,
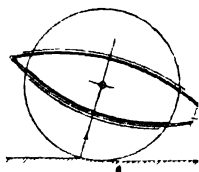
FIG. 109.—Diagram showing Spring arranged to absorb Horizontal Shock.

certain improvements which can be brought about which would assist the cushioning of the sprung weight and reduce the impact on uneven surfaces. Up to the present time the leaf springs of most vehicles have been set horizontally, which allows them to take only vertical shocks. This is quite inadequate on bad roads, because when a wheel strikes a slope of a wave or pothole it produces a horizontal blow in addition to the vertical effect. The value of this horizontal impact depends mainly upon the speed of the vehicle. If therefore the angle of the spring is such that it takes up the resultant reaction from the ground, i.e. the resultant of horizontal and vertical forces, the saving to the road and the vehicle will be considerable. An approximate idea of the angle required may be obtained by selecting a good average speed of about 20 m.p.h. The suggested arrangement is shown in Fig. 109.

Figure 110 shows a comparison of deflection in inches against

static load in tons on four different springs, and indicates that
generally the ratio may be shown by a straight-line curve.

Another factor of importance in connection with leaf-springs
is that of lubrication. For the most part the springs are
unprotected and exposed to the weather, thus causing the
individual leaves to become rusty and subject to considerable
friction. This stiffens the spring and renders it non-sensitive to
road deformation, which in effect amounts to a large increase of
unsprung weight.

In order to obviate this all leaf springs should be lubricated
periodically, so that the grease applied becomes a medium
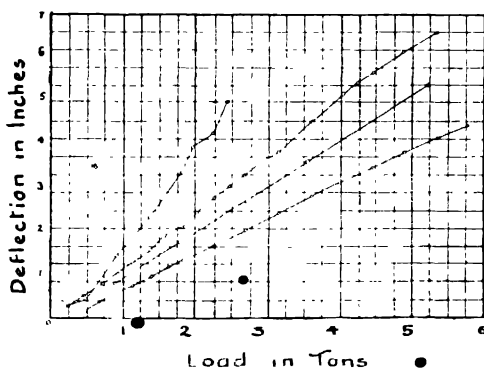
FIG. 110.—Comparison of Spring Deflection vs. Static Load.

between each leaf. Special covers are obtainable for the purpose
of retaining grease in the spring and keeping dust and grit out of
them. The use of these covers should be insisted upon by all
owners of vehicles, and indeed by the road authorities themselves.
There are many excellent devices on the market for assisting the
lubricating of springs which will obviate the necessity of jacking-
up the body of the vehicle and separating the leaves inde-
pendently for greasing—a practice which, although troublesome,
is to be commended as being thoroughly reliable.

Wheel-base and Rear Overhang.

It has been shown that a long wheel-base brings about
steadier running on the road. Clearly, then, a variation of wheel-

base of traffic passing over the same highway would have a
beneficial effect as compared with vehicles having the same
wheel-bases. There is obviously a limit to the length of wheel-
base for a vehicle ; a long wheel-base vehicle requires a greater
width or space for turning, and difficulties when turning into
narrower carriageways may arise owing to the rear wheels cutting
in with a sharper curve. The amount of overhang at the rear of a
motor vehicle naturally determines the relative proportions of the
load coming upon the rear axle. It also may increase the vibra-
tion of the rear part of the load to a serious extent. The portion
of the load behind the rear axle has a lifting tendency on the front
axle, and it would appear therefore a better arrangement to have
the centre of the load as far in front of the rear axle as is practic-
able. A long overhang is a great danger in case of rear skidding
and is to be deprecated. The Author has personally seen
accidents happen in this way, the rear part of the vehicle swing-
ing round and doing damage on the footpath, to pedestrians, or
to lamp-posts and similar obstructions.

Differential Gear.

As shown elsewhere it is extremely doubtful whether this
feature of axle design is as good for the road as for the vehicle ;
indeed, it is not always a good thing for the vehicle, because one
wheel only may be driving or braking and not the other—a
condition of things likely to produce skidding. Where the wheels
are driven without a differential gear, both wheels drive or brake
at the same speed and the only disadvantage is when turning.
With a long wheel-base vehicle the slipping will not be serious
for the tyre or the road. Many racing motorists prefer the axle
without differential, on account of the fact that no power is lost
through one wheel racing.

Centre of Gravity.

A high centre of gravity of a loaded or unloaded vehicle should
be avoided in all vehicle design.
A low centre of gravity means greater steadiness in running
and less rear vibration, and produces a much safer condition of
things for all vehicles on the highway.

The Four-Wheel Drive (F.W.D.).

The references made elsewhere to the destructive effect of rear-wheel driving (R.W.D.) naturally lead to the conclusion that some other form of drive might be less objectionable. The four-wheel drive, or F.W.D. (Fig. 111), as it was called during the Great War, seems to offer many advantages over the rear-wheel drive The effort at the driving wheels is reduced at least 50 per cent, and the mass of the vehicle is being jointly pulled by the front wheels and pushed by the rear wheels. This eliminates almost
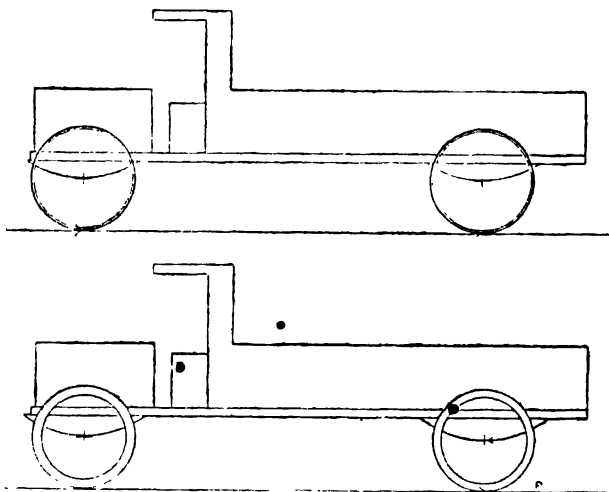
FIG. 111.—(Top) Four-Wheel Drive (F.W.D.), Solid Tyres, and (Bottom) Rear-Wheel Drive, Pneumatic Tyres.

entirely the "rear-axle kicking" referred to in Fig. 93 and the tendency of this type of vehicle to create waves is very small indeed, as also is that of the R.W.D. pneumatic-tyred vehicle (Fig. 111). In any case the friction and wear of the wheels and road surface is very much less than that of the R.W.D. solid tyre, and the saving in fuel and road wear must inevitably be very considerable.

Unfortunately, desirable as the F.W.D. is, there are mechanical difficulties which retard its general adoption. The drive through the front axle to the steering wheels is not nearly so simple as

that through the rear axle; nevertheless, the F.W.D. is a sound proposition and will become more perfect in course of time.

Three-Axle Truck.

A splendid example of distribution of the drive through two axles is afforded in the impact tests of the U.S.A. Bureau of
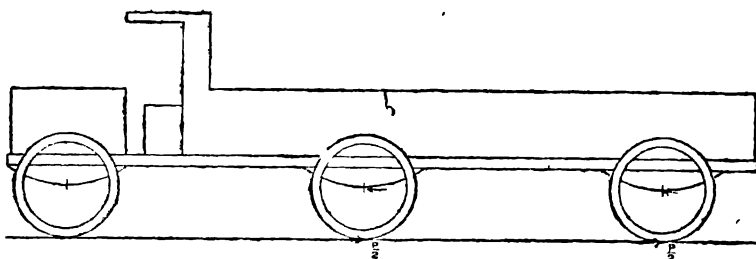
FIG. 112.—Six-Wheel Vehicle with Four-Wheel Drive and Pneumatic Tyres.

Public Roads, with a special six-wheeled truck having two rear driving axles and pneumatic tyres, as shown in Fig. 112. The weight was distributed over the four rear wheels instead of two as on the ordinary vehicle. The tests show that the impact is
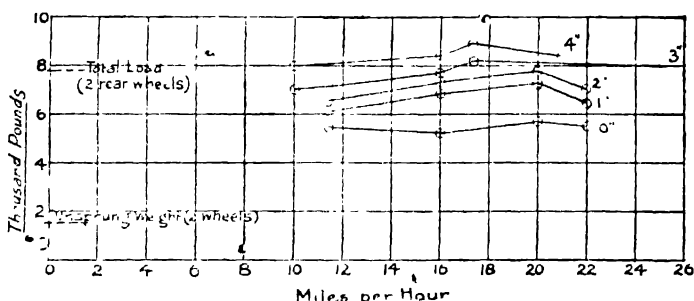
FIG. 113.—Graph showing the Combined Impact of Two Left Rear Wheels of Six Wheel Vehicle.

practically constant for speeds between 10 and 25 m.p.h., and that the combined impact for the two left rear wheels is less than the total load on those wheels (Fig. 113).

The Renard train has proved the soundness of the theory of driving from as many wheels as possible, and it is readily conceiv-

able that the principle could be applied with success to a wagon and trailer so that eight wheels are driving instead of two as at present. Electric or petrol-electric propulsion seems particularly well adapted for this purpose.

The " Scammell " six-wheeler has the middle axle only driving, and the rear part of the vehicle is merely hinged and acts like a trailer. It permits of carrying heavier loads than the two-axle vehicle (Fig. 114).

Spring Draw-bar for Trailers.

As a general rule it is very much more economical to haul trailer loads behind a motor lorry than to run solo. In all cases it is advantageous to introduce a spring draw-bar behind the lorry in order to make the pull from the trailer practically
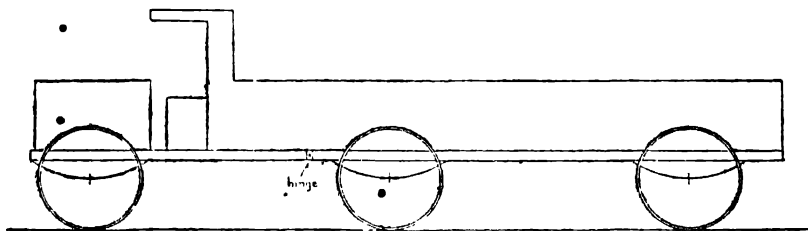
Fig. 114.—Scammell Six-Wheel Vehicle on Solid Tyres.

constant when on a bad road surface. It steadies the pull on the trailer, the effect upon the lorry and upon the loads of both, and in addition less damage is done to the road surface.

Loadometers.

These instruments are portable jacks intended for testing the axle weights of vehicles on the road by placing under the axle and raising it slightly from the ground. They form a very much simpler arrangement than the ordinary weighing machine, although so far they are not in use in this country. Many of the older weighing machines are too small to accommodate complete vehicles, either for width or length, and are quite inadequate to deal with modern traffic ; some other system like the loadometer might therefore be introduced with a view to solving this problem.

CHAPTER XVII

UNDERGROUND WORK AND REINSTATEMENT OF PAVING

THE question of laying or renewing underground mains in the public highway has been until recently a fairly simple process. The rapid increase towards perfection of modern roads has been accompanied by an equally rapid development and extension of underground mains of various kinds, especially in connection with the use of electricity. The principal mains which have to be considered in connection with highway work are :—

1. Sewers.
2. Surface and foul water drains.
3. Water or hydraulic power mains.
4. Gas mains.
5. G.P.O. telephones.
6. Electricity mains.

All these varying classes of mains have their individual systems, each with innumerable connections to property.

It is possible that there will be a further development of underground works in large cities, as, for instance, along the lines of a parcel delivery system.

Where very large sewers or subways have been laid the problem of reinstatement is not of so much importance.

The modern road, whether it be of a tar or bituminous nature, or concrete foundations or surface, should not be interfered with except under very urgent circumstances. The cost of providing a suitable road crust for modern traffic is so very heavy that no authority can afford to have it disturbed whilst the surface is in good condition. Once disturbance has been allowed to take place it is exceedingly difficult to bring the road to its former

condition. Cross trenches are particularly objectionable, as they set up that vibration which produces corrugation.

The tendency in road construction to-day is to lay more and more concrete, foundations and surface. A very great mileage of granite setts on a concrete foundation already exists on the main roads of this country, and this mileage is increasing annually. A disturbance of a road of this type for the purpose of laying a main longitudinally cannot be made good until the ground has consolidated itself, and this delay necessitates constant attention and the raising of the settled paving to maintain conditions of safety—all of which is naturally a very expensive process. The old adage that prevention is better than cure is certainly applicable to underground works along the public highway. In this respect it is advisable for the local authorities contemplating the execution of works requiring concrete slab construction to communicate with the various departments responsible for underground works in the particular area, in order to ascertain as far as possible their respective intentions for the near future.

There should be no difficulty in securing a working arrangement between the various departments concerned, when it is realized that it is to their mutual interest to anticipate work, and so economize on their costs of reinstatement.

There is no satisfaction to either the road or mains authorities in having to break a concrete slab in order to lay a main.

The Importance of Depth.

The depth at which the underground services are laid affects the disturbance of pavements to a considerable extent. In the case of the shallower mains it is imperative to obtain access from the surface for the whole length of the main, but in the case of deeper mains, such as sewers and certain water mains, the breaking-up of the road surface may in many instances be avoided by tunnel work and occasional sinkings in various places along the route. Water mains are usually laid moderately shallow, as also are gas mains, electricity and telephone cables; especially is this so where the mains can be placed under the footpath, in which case the highway engineer is not seriously concerned, except in so far as crowding the space underneath the

footpath may drive the future pipe lines into the carriageway. It is clearly advisable to have all these mains under the footpath if possible, so that access may be obtained in an inexpensive manner and without interference to traffic. The rights of pedestrians should also be considered, and any interference with the footpath should have the consent of the road authorities, who should insist upon proper provision being made for foot passengers and access to shops and business premises.

Subways for Underground Work

In town areas the objections to disturbance of carriageway and footpath are particularly serious, and it is necessary to devise some method of minimizing the inconvenience to pedestrians and traffic as much as possible. The most important proposal which
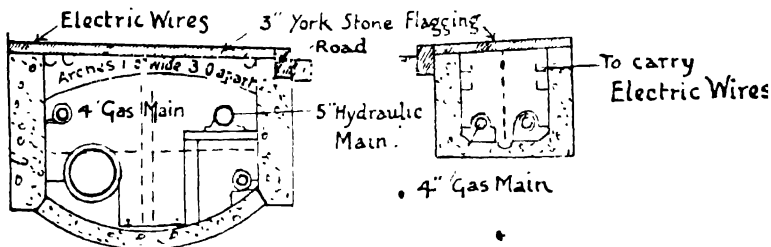
FIG. 115.—Shallow Subways for Gas, Water, and other Mains.

has yet been made towards the solution of this problem is the provision of subways to contain gas, water, electricity, and P.O. mains, as shown in Fig. 115. This would enable access to be obtained throughout the whole length by entering the subway at manhole stations. In the centre of the city such subways would permit of renewals, repairs, connections, and the fullest possible access and inspection throughout the whole length without any interference or inconvenience on the surface.

The initial cost of the subway should be borne by each of the departments concerned, and whilst this expenditure may appear to be greater than the cost of laying the same mains in the ground under the footpath, the subsequent saving will more than repay the cost incurred in the construction of the subway. The dimensions of the subway should be sufficient to contain several lines of

electricity supply cables of various pressures, Post Office cables, and gas and water mains up to 12-in. diam.; the larger mains for gas and water and the sewer should be excluded from the subway, as they usually do not require so much attention nor so many connections as the smaller mains. Space should also be left to allow sufficient clearance for a man to pass along easily.

The provision of a subway in town areas would, among its other advantages, largely prevent the external corrosion of the pipes or mains.
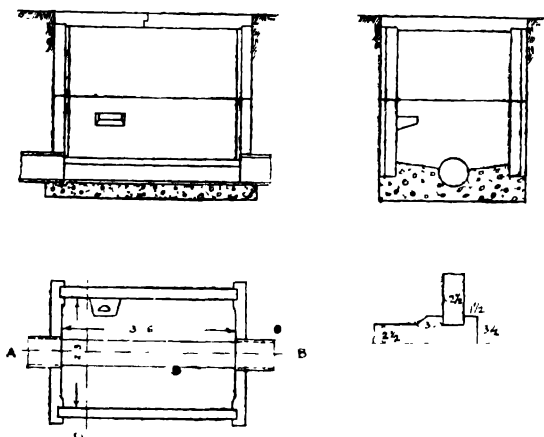
FIG. 116.—Detail of Concrete Slab Inspection Chamber.

Manhole Shafts.

These should be provided at convenient intervals and at important junctions of mains, so that access for pipes and other materials may be obtained without having to travel any great length of the subway. These access shafts are comparatively inexpensive—especially when constructed on the principle of the concrete slab chamber shown in Fig. 116—if they can be arranged to occur on the footpath and a light manhole cover utilized. Manhole covers in the carriageway are most objectionable; they require to be of a very heavy type to resist impacts from road traffic, and almost invariably they work loose or develop some play which may render them dangerous and unsafe. Moreover,

R.E.—Q

the existence of a rigid-frame manhole cover in a tar or bituminous road crust may become the starting-point for wave formation. Various methods have been devised for eliminating this latter difficulty ; usually setts are paved round the cover in order to prevent the formation of holes which invariably result at the juncture of an iron cover with a road surface.

In the case of iron covers in a road surface paved with granite setts upon concrete or concrete alone this difficulty does not arise in the same degree, although the cover itself will be liable to develop play. In any event manhole covers should be avoided on the carriageway, if this is possible, for sewer work where access is only required infrequently. It would be more economical to have the access cover beneath the road surface in such a position
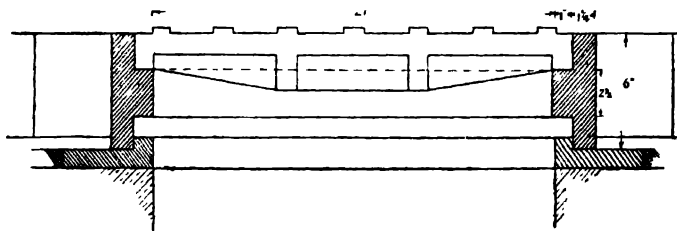
FIG. 117.—Detail of Renewable Manhole Cover.

that it could readily be located when required. A submerged manhole shaft could be covered with a blank concrete slab, and this method would eliminate the wear which occurs round exposed iron covers. Special footpath markers could be utilized for denoting the exact position of these submerged shafts.

A manhole cover has recently been designed and patented in Chicago by Mr. F. Shanley, which is in three parts, viz. base, ring or kerb containing two ledges on the inside face, and the lid. The arrangement—shown in Fig. 117—allows of the reversal of the kerb when one ledge is worn without disturbance of the paving, and also renewal of the kerb at a nominal cost.

Side chambers are very often useful in obtaining access to subways, sewers, or other culverts where it is difficult on account of traffic to enter them from the top, but they are necessarily expensive.

Mains on Footpaths in Urban Areas.

In the case of suburban areas where wide footpaths are provided on each side of the road, the mains can be laid fairly inexpensively at shallow depths under the footway.

The tendency of housing development to-day is to provide wider footpaths and somewhat narrower carriageways than hitherto, the former allowing for a grass or gravel margin. This feature is of considerable value to the mains authorities, because the disturbance and reinstatement of these margins is a comparatively trifling matter.

There are some water authorities which prefer to lay their mains in the carriageway, the reason being, apparently, to get as far away from buildings as possible. This reason, however,
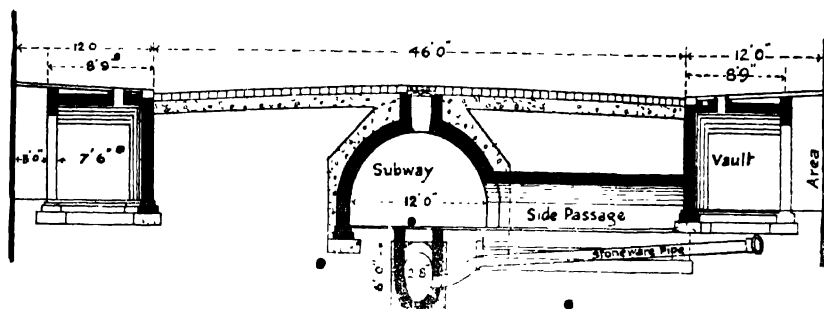
FIG. 118.—Section of Subway, Victoria Embankment, London.

cannot be applied to modern housing development, which allows an ample forecourt or front garden space in addition to the wide footpath. Fire hydrants may be fixed on the footpaths, providing that some concrete or sett paving is laid around to take the water to a channel in the carriageway. The sewers may be laid away from the carriageway in cases of this kind, although cross drains for gullies will be required, as is the usual case when the sewer passes down the centre of the road; it is particularly easy to accomplish this on some of the lesser or cul-de-sac roads on housing schemes. Where cross-fall from one side to the other is employed and gullies on the lower side only are provided (Fig. 63) there need be no cross drains or sewer whatever in the carriageway.

Subways have been constructed in the past, notably in London (Fig. 118), Nottingham, and Paris. Those in the City of London are probably the most complete of their kind, but from their extent and special circumstances caused by the varying levels of intersecting streets their construction was very costly. Accommodation for future extensions of pipes and mains was provided,
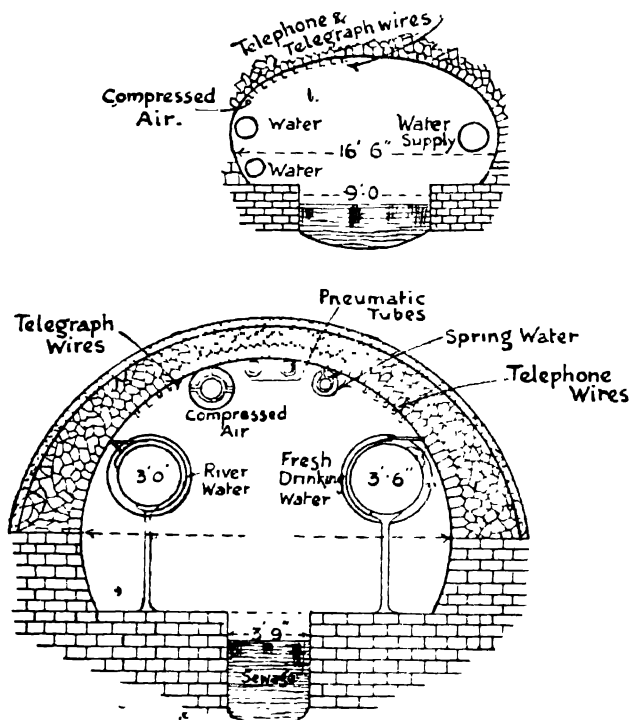
FIG. 119.—Sections of Subways, Paris.

and also convenient access. The subways are lighted by gratings in the footways fitted with glass lenses placed at intervals of 4 ft., and in addition to this artificial light is provided. Water pipes are supported by iron chains, the gas, electricity, and other pipes are carried on wall brackets, and ample space round each of the pipes is allowed for access purposes. The water mains are provided at intervals with stop-cocks, air valves, and emptying

cocks which discharge into the sewers, and also with hydrants
for the purpose of washing out the subways. The temperature
obtaining in subways is of special importance during cold
weather. The minimum temperature of the average subway will
be just above freezing-point.

The Nottingham subways are ventilated by means of gratings
at the surface level of the street placed about 48 ft. apart, also
by three side entrances and by open gratings in a refuge at the
lower end of the street. Brackets are fixed in the subway for
carrying pipes, as in the case of London. An extensive system
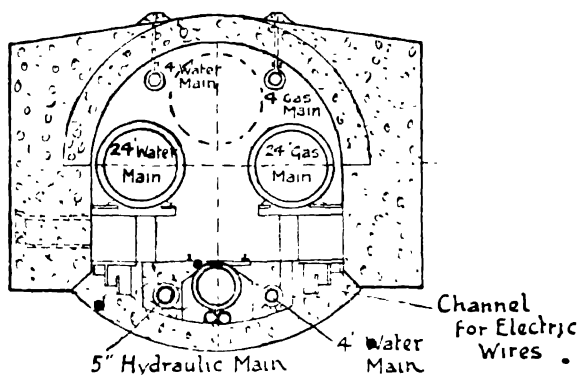
FIG. 120.—Example of Concrete Subway under Carriageway.

of subways exists in the City of Paris. Figure 119 shows the
construction of a main sewer and subway in the Boulevard
Sebastopol. This tunnel is 11 ft. high and 16 ft. wide ; two large
catchpits are constructed for the use of boulders, sand, stones,
and other rubbish which have been washed down the numerous
channels that empty themselves into the collector and settle into
these pits. The sewage runs in the centre or side channel 5 ft.
deep and 3 to 4 ft. wide. Pipes are provided for carrying fresh
water and river-water supplies, also electricity and other cables,
and pneumatic tubes.

An example of construction in concrete of a subway suitable to
carry mains under the carriageway is shown in Fig. 120. In this

case provision is made for all mains, and a small rail track is laid in the middle for haulage of pipes, etc.

Thrust Borer.

This apparatus enables horizontal borings to be made without disturbance of the road surface, excepting, of course, the sinking for the starting-point. It is possible to make borings 50 yd. in length from one setting and to thread in 6-in. earthenware pipes ; in the case of smaller diameter pipes the process, in suitable ground, is very rapid and economical. It is very convenient to use for passing under tramway tracks and busy thoroughfares where traffic cannot easily be interrupted. It is necessary to make careful enquiries regarding all existing mains before using this apparatus, in order that the borer will not foul them in the process of boring.

Reinstatement of Bituminous or Tarred Macadam.

In the absence of subways for mains and with insufficient footpath space to eliminate the necessity for laying underground mains in the carriageway, the reinstatement of road surfaces after disturbances for repairs or renewals of the mains requires careful and judicious treatment by the road engineer. The responsibility is divided between so many different authorities and contractors that it is difficult to ensure efficient filling-in of the trench. If possible the road engineer should place an inspector on the work to supervise on his behalf the reinstatement of the disturbed area and to prevent the possible interference with other mains. Where this is not done the workmen employed on excavation and filling will naturally become careless and haphazard in their methods, which will result in increased expenditure for the authorities.

If, for example, a trench is filled in during dry weather, carelessly punned and not watered, the surface of the road will continue to settle for a very considerable time to come, even though the paving be made temporarily safe at frequent intervals. It is incumbent upon each local authority to be particularly strict on this point of refilling the trench, and it may perhaps be cheaper 'in the end for the mains authorities who are responsible for the

reinstatement charges to carry out the necessary precautions as laid down by the local highway authorities.

It is a sound proposition to have the filled-in material thoroughly well watered and punned as the filling-in of the trench proceeds. Another point which occasionally upsets the calculations of the mains authorities is the subsidence of the paving immediately adjoining the trench. This is what the road engineer may expect to occur, and the amount of the subsidence will depend on the nature of the ground, depth of the trench, and the time that the trench is open.

In the case of reinstatement on tarred or bituminous surfacing the temporary reinstatement is done by filling in the road material well above the level of the road to allow for settlement. As regards cross trenches this is not very satisfactory, as the material works itself into a ridge and causes serious impact from traffic upon the untouched road immediately adjoining the trench. So far as longitudinal trenches are concerned constant inspection and raising of the surface may be necessary in order to maintain the road in a condition of safety. The use of a road roller will assist in consolidating the material, and it is a matter for the road engineer to determine at what period the reinstatement can be done permanently.

Reinstatement of Sett Paving.

With regard to the reinstatement of sett paving on a non-rigid foundation similar precautions are necessary ; the paving should be laid " dry," i.e. without grouting of the joints, in order that they may be raised easily after settlement has taken place. Cinders are usually applied temporarily both for the filling of the joints and the covering of the reinstated section. When settlement has practically ceased, the setts can be permanently reinstated with a proper pitch grouting and chippings. The actual period after which settlement should cease may be a matter of several years, and if possible the engineer will reinstate the paving with grouting long before final settlement has been attained. Where this happens and a very slow settlement is taking place the carriageway should be reasonably safe for traffic, although it can never be regarded as a perfect surface.

Reinstatement of Concrete Slab Paving or Foundation.

The reinstatement of either a concrete foundation or surface is usually a matter of some anxiety to the engineer. In the first place, the concrete cannot immediately be reinstated owing to the slow process of settlement, and the edges of the existing concrete are in danger of breaking off owing to the partial subsidence of the sides of the trench. Secondly, when the reinstatement of the concrete is effected there is a possibility that some further settlement underneath the slab may occur and so cause the concrete to crack. Some means, therefore, must be found to circumvent these difficulties. Perhaps the safest plan is to distribute the weight over the undisturbed foundation by reinforcing the concrete with a suitable fabric and bridging the trench by hacking away the sides. The foundation itself should not be liable
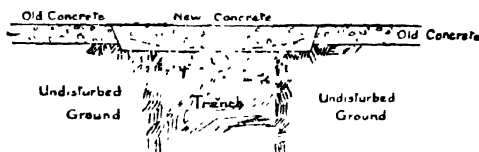
FIG. 121.—Section showing Reinstatement of Concrete Slab over Trench.

to subsidence as the result of the drawing-in or drawing-down action of the trench.

With a deep trench this might necessitate reinstatement of a very wide span and this would obviously be a very expensive operation. With a shallow trench permanent reinstatement can be performed within a very short time after the filling ; if a rough concrete is placed in the trench as filling the road surface may be relaid almost immediately.

Some irregularity of the joint with the existing concrete is an advantage, as this may be arranged to give a greater span in some parts than in others. Where the original concrete slab has been reinforced it may be possible to take advantage of the projections of the steel in order to link up with the new reinforcement. Another method of reinstating concrete is to lay it some 2 or 3 in. thicker than the original slab with the reinforcement passing

under the thinner slab ; also the sides of the old concrete may be stepped or sloped to give a key for the new slab (Fig. 121).

There is an erroneous impression amongst some engineers that a reinforced concrete slab is much more difficult to break through than a plain concrete slab, even though the latter be of greater thickness. In 1915 a test was made in London, in connection with the gas companies' objection to reinforced concrete, to determine the relative time required to break through a 6-in. reinforced concrete slab and a 12-in. plain slab under exactly similar conditions. The time taken for the unreinforced slab was much greater than that taken for the 6-in. reinforced slab.

As a precaution against the damage from the bursting of a water main below concrete, iron tubes may be placed vertically above it at intervals in the slab to allow the water to rise without lifting the pavement.

CHAPTER XVIII

LABOUR-SAVING MACHINERY

AMONG the developments accelerated by the Great War the advancement of labour-saving machinery takes a prominent position, and but for the sheer necessity of that period many of the machines which are now in everyday use would have remained still undiscovered.

At the same time, we have the fact that throughout history and against mechanical invention superseding hand labour there has always been a large volume of prejudice on the grounds that labour-saving machinery creates unemployment. A close study of the question, however, will reveal that in the long run it has the opposite effect and creates employment. *To perform work cheaper by machinery reduces the cost of living for everybody and benefits the whole community.* The useful employment of a machine may cause, in a purely local sense, temporary unemployment, but in the long run and in a national sense the reverse is the case.

It is well, therefore, that the road engineer should be conversant with the cause and effect of mechanical effort in the carrying out of road works. There is still vast scope for the further employment of machinery in this country ; a brief résumé of some of the machinery available for road construction is given below.

Steam Shovel Excavators.

These machines are widely used abroad for a variety of purposes. They may be employed for a deep cut or for shallow excavation in preparing a road bed or excavating a broken-stone roadway. By means of an adjustable boom and jib ties the required depth, i.e. up to about 20 ft., can be regulated. Special

devices are necessary for shallow working in order to leave a smooth even surface.

Other machines which may be mentioned are the small revolving steam shovels equipped with about ½ cu. yd. capacity dippers, and the electric power shovel which can be readily adapted to load or unload materials from trucks, barges, etc.

Drag-line Excavator.

This machine may be employed for excavating more or less loose materials such as gravel or loam, and consequently may be used for grading roads where the earth is suitable. The excavator has a tip bucket suspended from the boom by rope, and on touching the ground it is dragged towards the machine, thus gathering the excavated material in its path ; it is then lifted, swung round, and discharged as required.

Ladder Excavators.

This type of machine consists essentially of a series of toothed cutters and buckets attached to endless chains in an adjustable boom, which enables it to excavate to various depths and angles.

Trench Excavators.

Trench-digging machinery is used for excavating sewer, water, gas, or other pipe trenches up to a depth of about 20 ft. Trenches from 12 in. to 7 ft. wide may be excavated at a rapid rate with these machines. The " wheel "-type excavator differs from the ladder type in so far as the cutters and buckets are mounted on a vertical wheel, and by use of a steering-gear and grade-control right- or left-hand curve trenches may be cut and the trench given the necessary slope or gradient. These excavators are usually propelled by caterpillar traction which enables them to negotiate soft or uneven ground. In this class should be included scraper excavators and grabs.

Back Fillers.

The trench excavator may be equipped with a back filler, which consists of a scraper attached to a wire cable wound round the drum of a steam-engine or light crane. The scraper is lifted to a

position behind the heap of excavated earth and dragged to a position over the trench where the loose material is deposited.

The men employed work directly behind the digger, and the material is replaced on the newly laid pipes almost immediately, and thus progress is extremely rapid.

Elevators or Bucket Loaders.

Where large quantities of loose materials have to be loaded into trucks or motor wagons it is economical to employ a mechanical loader. This consists primarily of a belt or an endless chain carrying a series of buckets which dig into the heap of material and carry it upwards to deposit it at a higher level into the conveyance. The rotary disc type of bucket loader is extremely valuable, possessing as it does two horizontal steel discs set close to the ground and revolving inwards towards the buckets, and so rendering the machine a self-feeder. A large quantity of material can be dealt with by this loader in a short time.

Conveyers.

These are usually belt conveyers, which are capable of raising material at a comparatively small angle of elevation and where the height to be lifted is not great.

Portable Crushers.

The employment of a crushing plant in connection with road works is an essential feature of modern practice in this country ; it frequently happens that existing boulders or broken concrete may be re-used if the material is put through a crusher. There are various kinds of crushers in use at the present time, chiefly of the Jaw Crusher and Gyratory types. The Jaw Crusher, which may be adjusted to produce various grades of coarse aggregate, may be obtained as a complete unit or as a separate machine to be driven from a steam roller or petrol plant. The Gyratory crusher breaks the material between the toothed faces of two cones, the crushing effect being obtained from a gyratory motion of the cone by special gearing. Disintegrators or Cage Mills, consisting of a pair of cages revolving in opposite directions

and breaking the materials between them, are also employed for producing the coarse-graded material. The rotating shaft carries hammer-bars loosely pivoted like the spokes of a wheel, and delivers a rapid succession of blows on the material contained on a grate until it is small enough to pass through it.

Portable Crushers and Bins.

The portable bins in connection with crushing plant are metal lined, of a capacity up to 25 tons. They are mounted on wheels, the complete plant consisting of a crusher with reversible joints and dust-proof bearings, together with a screen and elevator fitting into the bin.

Road Rollers.

The road roller is probably one of the oldest labour-saving machines introduced in connection with road-making. There are various types in use to-day, mainly driven by steam or petrol. The petrol road roller is becoming more popular with its increasing reliability ; it has a high rolling capacity and eliminates many of the fuel and water troubles inherent in the steam roller. At the same time steam road rollers have been brought to a high pitch of perfection ; for instance, the dead centre position of the single-cylinder engine with its single crank has been superseded by the cylinder and piston valves being placed side by side with the cranks set at an angle of 90°, so that the engine can be started even on a steep incline by simply opening the throttle. This ensures an even turning moment, as the engine runs smoothly and without vibration so that a regular rolling effect is obtained, and the possibility of wave formation reduced to a minimum. Where sharp curves or narrow thoroughfares are to be rolled it is advantageous in the usual ordinary three-roller type to provide a compensating or differential gear on the rear axle.

The rear wheels of cast-iron and disc type should be provided with frost stud holes, filled up when not in use, particularly for the driving rollers. The front rollers should overlap the track of the driving rollers to ensure that no space is left unrolled.

Spring scrapers fitted to the back and front of the driving

rollers are useful in removing material which has adhered to the rim.

Steam-rollers may readily be equipped with a liquid-fuel apparatus for burning crude oils or residuals ; also the provision of water sprayers for the front and rear wheels is an advantage.

The tandem roller is of recent design, and has proved itself particularly easy to handle and most effective in repairing or finishing asphalte roads in place of the horse-drawn or hand rollers previously employed. The tandem roller may be driven by either steam or petrol with the engine fitted low on the frame and a main steel spare gear drive. This feature ensures smooth rolling and rapid turning, and consequently an increased rolling capacity and also a reduced tendency to form corrugation. The lighter rollers may be equipped with a water-ballast tank on wheels, which enables the weight to be varied with a range of about 2 tons.

Scarifiers.

No road-roller equipment is complete without a scarifier, either attached to the roller or hauled as an independent machine by means of draw-bar or other attachment. The utility of the scarifier is so obvious that no elaboration is needed at this juncture. It may be fitted to an 8-ton roller, in which case it will be of the 2-tyne type, but is more suitable for the heavier rollers such as 10 to 12 tons, when the 3-tyne scarifier may be fitted.

The tool holders are usually of cast steel and reversible, being raised or lowered by means of a hand-wheel operating a steel worm gear. The depth of cut can be regulated at will and the tool holder readily raised to pass manholes, crossings or other obstructions.

Road-Grading Machines.

These machines—mostly used abroad—are useful for taking off loose material or keeping the shape of cinder or gravel roads. They may be either horse-driven or attached to a traction engine or roller.

Various types of simple scrapers can be used for dragging loose materials short distances from the carriageway.

Washing Plant.

The importance of clean material for concrete road work has brought about the manufacture of portable washing plant. In particular, the cleanliness of sand is often very doubtful, and it is generally a sound proposition to wash the sand and coarse material in order to secure the best possible results with the finished concrete. One type of washer consists of a rotary drum slightly inclined, or a stationary drum containing a worm screw with a stream of water washing down and over it so that the material works up the drum to an outlet at the top, the flowing water removing the clay or other foreign matter into suspension and carrying it away.

Another method of washing sand is by throwing the material on a vibrating screen which has a stream of water flowing over it, or else is suspended horizontally in a tank of water. In the simplest form sand may be washed in a V-shaped trough containing water which is continually fed at one end and which overflows at the other. A combined washing and grading machine, petrol driven, has been used for washing the excavated material from old macadam roads in order to render the stone suitable for concrete aggregate. The arrangement of a screening plant usually consists of a perforated cylinder containing 2, 3, or 4 compartments according to size, so that the largest pieces are separated in the first compartment and the material then can pass into the second compartment, and so on progressively.

Concrete Mixing and Distributing Plant.

This consists of a lattice tower at the base of which the concrete is mixed and afterwards raised in a hopper which is on the tower itself. From this hopper the concrete flows by gravity into a long spout placed at a suitable angle and delivering to the point desired. This spouting may be moved for a considerable range horizontally or vertically and is readily adaptable for road work.

Large Concrete Mixer with Distributing Boom.

This machine (Fig. 67) enables one man to produce as much concrete per day as a large number of men working by hand.

It is generally driven by steam or petrol, and consists essentially of a skip or hopper which can be raised or lowered at will and which delivers the various materials into the mixer. The finished product is run out in a carrier or bucket along the distributing boom, which can be adjusted to reach within limits any portion of the road. The machine is self-propelling and extremely economical in its working.

Small Machine for Mixing Concrete or Tar Macadam.

Generally speaking, the small mixing machine is not as economical in man power as the one previously described, but it is of great utility where moderate quantities are involved. As with the larger machine this is controlled by one man only, and the measured materials are placed in a hopper which delivers them into the mixing drum. The necessary water is added and the drum rotates until the mixing is completed, after which the contents are delivered into a truck, barrow, or small vehicle. The smaller type of machine usually has a capacity of from 3 to 7 cu. ft.; such mixers are readily adaptable for mixing tar macadam, the dry stone being placed in the drum together with the hot tar and the whole rotated and emptied as in the case of concrete.

A Concrete Breaker.

The breaking of concrete road surfaces or foundations by hand is usually a very laborious and expensive matter, and in order to render this work more economical a portable compressed air plant has been designed, which effectively breaks the concrete at a very nominal cost. Incorporated with the air-compressor plant is the excavating pick with T-handle and trigger throttle valve (Fig. 122), which is held by one man who probes or breaks into the concrete. The valve has a short lift with large free-air passages, thus imparting a quick, sharp action to the piston or hammer and a rapid cutting speed. The succession of blows of this tool rapidly breaks the concrete into more or less small pieces so that it is ready for removal. The cutting tool consists of either amoil point steel or a chisel edge steel. The steel is first driven in about the middle of the trench which spalls off an irregular V-shape piece. Two more cuts are made about 3 in. from each side

Throttle
Lever →

Throttle Valve

Handle

Cylinder Cover

Valve

Valve Seat

Cylinder

Piston

Anvil Block

Cylinder Bushing

Front Head receiving
cutting tool
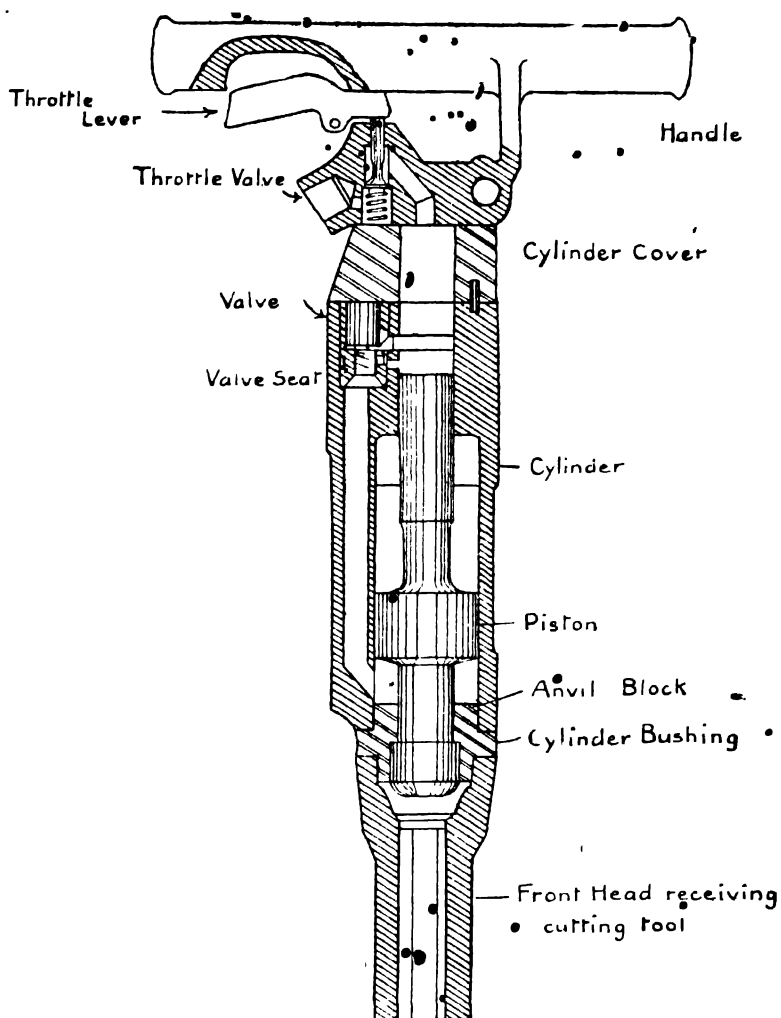
Fig. 122.—Detail of Compressed Air Paving Breaker (Ingersoll Rand pattern).

which removes the remainder of the concrete from that line. One distinct advantage of this pick plant is that for trench work the width may be reduced to a minimum, and the remaining concrete left free from cracks which would be more likely to occur if the work were done by the hand process. The apparatus may be used for excavating macadam, ballast, hardcore, or similar foundations.

Dryers and Heaters.

This plant usually consists of a simple form of shallow tank or container with a covered top and fire-heating arrangement beneath. It is most useful for drying fine aggregate or chippings when required for the bituminous work ; its use will add somewhat to the cost of the work, but as against this a greater certainty of well-coated material is obtained.

Tar Macadam Plant.

This plant is self-contained and comprises tar-melting tanks, elevator, mixer, dryer, and barrow hoist. The stone is dried, heated, elevated, and mixed with the correct proportion of heated tar, and has a capacity for an output of 10 to 50 tons per day. It may be operated either by steam or petrol.

Truc-tractor.—This vehicle is intended for the rapid removal of materials such as concrete, sand, stone, etc., and for this purpose it is fitted with an automatic end- or side-dumping body of a capacity of about 24 cu. ft. The load is dumped and the hopper recovered by the driver without his dismounting. The vehicle is petrol driver and is mounted on three wheels, being thus very easy to manipulate for turning within a small compass.

Dump Wagons for Transporting Material.

These cars travel upon a light railway and are so arranged that the body may be set at any angle desired, both for loading and unloading. They are used for transporting excavated material, ballast, sand, stone, etc., and are capable of delivering the dry concrete materials straight into the hopper of a mixer. They may be obtained in various types and suitable for different

gauges of rails. The " Jubilee " type of wagon is very largely used for works of any magnitude in this country. The wagons or trucks may be propelled by one or two men, or drawn by horse or steam locomotive.

Caterpillar Tractor for Difficult Haulage.

This machine is particularly useful in districts or any localities which are a considerable distance from a railway, and where it is necessary to transport large quantities of material over unprepared ground. It consists of a powerful tractor with caterpillar mounting, and a number of trailers similarly mounted so that the train may be hauled over bad ground or unfinished roads with safety.

The Fordson Tractor is an example of an economical tractor which may be utilized for hauling trailers over good ground and also along the public highway.

Portable Lift Plant.

This consists of a small three- or four-wheeled electric truck, similar to the trucks used on railway stations, carrying small gauge boxes of dry materials on a movable platform which is lifted on the truck within limits as required. It is operated by one man, who travels on the truck, and dispenses largely with the use of wheelbarrows. The use of this vehicle undoubtedly reduces the cost of concrete work where it can be introduced.

CHAPTER XIX

ORGANIZATION AND ADMINISTRATION

ALL work relating to land or property between the boundaries of public highways comes under the jurisdiction of the highways department, whether it be a municipal borough, district council, or county department. Generally, the county highways authority is concerned in the upkeep of first- and second-class roads in the whole area of the county, but excluding the large boroughs which have their own department for the maintenance of the whole of the roads in their respective areas. This work includes the design, construction, and maintenance of all highways, including sidewalks and highway bridges. The control of the underground structures and encroachment, including conduits, pipe lines, service connections, subways, projections such as steps, standards, lamp-posts, and pillar-boxes, petrol pumps, and also overhead works belongs to the highway department. Also :—

Permits and licenses for temporary obstructions and disturbances.

Cleansing of the streets and roads.

It may not happen that the whole of this work devolves on the highways department, but it is certain that the above items are properly within its scope.

The administration of the highways department for a large town or county area will come under the supreme control of the Chief Engineer assisted by :—

Deputy Engineer.

District Engineer.

Assistant-Engineers and Juniors.

Inspectors.

Foremen.

Timekeepers.

Tradesmen, including masons, joiners, bricklayers, pipe-
layers, motor drivers, carters, labourers.

In addition to this there will be a clerical staff consisting of :—

Secretary.

Correspondence clerk.

Chief clerk.

Other clerks, typists, and juniors.

Also an accountancy section comprising :—

Accountant.

Account clerks.

Materials clerks.

Cost clerks.

Juniors.

For smaller towns or counties this staff would be too large, but
the class of work indicated could be performed by a less number
of persons.

To ensure success in an organization of this character it is very
necessary to secure the right type of assistant for the sub-chief
positions, so that the " team " spirit is developed in the various
branches of the department.

Facilities should be afforded for each member of the staff to
make himself conversant with the general policy of the depart-
ment.   If necessary, written or verbal instructions should be
given to all assistant engineers, inspectors, and foremen in order
that while working in independent areas they will carry out a
common policy.

Mechanical Haulage.

One of the first considerations in road construction is the cost
of haulage of the road materials to and from the site of the works.
The organization of this haulage should come under the control
of the district engineer or possibly the transport officer.   For
economical running, the steam wagon or petrol lorry should work
the maximum mileage and number of loaded journeys and a

minimum of unloaded journeys, the object being to obtain as great a ton-mileage as possible per day. The driver of the vehicle, whether hired or belonging to the department, should be supplied with daily record forms in which to enter the following information :—

Number of journeys.
Time of arriving and leaving.
Whether loaded or unloaded.
Destination.
Nature and weight of load.

The mileage of the journeys should be filled in by the assistant-engineer or transport officer, and the ton-mileage should be obtained by multiplying the total daily load by the average of the loaded journeys. The cost of haulage per ton-mile is then readily obtained.

The daily work of the vehicle should be entered in a weekly form as shown below. It is undesirable to make comparisons of vehicles or day to day workings of a particular vehicle unless the entire details of the materials, facilities for loading or unloading, average length of journeys, etc., are also considered. The use of trailers, as far as possible, especially for long journeys, is to be recommended on the score of economy.

Unit Costs.

Unit cost records are necessary to ascertain the relative and total costs of each class of work and to provide data for the assistant-engineer in the examination of the progress of the work. This, in turn, also increases the sense of responsibility and public spirit of the men involved. Periodic measurements of the work should be made by the assistant-engineer at least once a week.

The unit cost for a work will be supplied by the cost clerks, after extracting the wages bill for each class of work, the area of which has been measured. The other costs, such as materials, are obtained when the unit cost of haulage is known. Upon completion, the whole of the work is measured and costs obtained for each particular operation. In the case of contract work, the

HIGHWAYS DEPARTMENT.

WEEKLY RECORD OF MECHANICAL HAULAGE.
(taken from Daily Time Sheets).

No. and type of Wagon................

Name of Driver................

District.

Week ending ....

Day.	Materials carried.	From.	To.	Total weight carried	Average weight per journey.	No. of loaded journeys.	Average miles per journey loaded.	Total mileage of loaded journeys.	Total mileage of empty journeys.	Total ton-miles per day.	Cost per ton-mile.	Remarks.
Monday												
Tuesday												
Wednesday												
Thursday												
Friday												
Saturday												
Totals for week												

Week ending..................

Day.	Materials carried.	From.	To.	Total weight carried	Average weight per journey.	No. of loaded journeys.	Average miles per journey loaded.	Total mileage of loaded journeys.	Total mileage of empty journeys.	Total ton-miles per day.	Cost per ton-mile.	Remarks.
Monday												
Tuesday												
Wednesday												
Thursday												
Friday												
Saturday												
Totals for week												

principal concern of the engineer is the progress and excellence of the work and its completion within the specified time limit.

Measurements will be taken for this purpose, and also in order to advance payments to the contractor at reasonable intervals. It is not proposed to treat contract procedure further, as it is outside the scope of this work.

Highways Accounts.

In the case of local authorities it is highly desirable to have a thorough and methodical system of keeping accounts for road works in order to arrive at costs quickly at any time, and also in order to present accounts to the Ministry of Transport (or the County Council where applicable) for grants towards expenditure. The diagram shown in Fig. 123 explains at a glance a system which has been devised by the Lancashire County Auditor's Department for adoption by highway authorities.
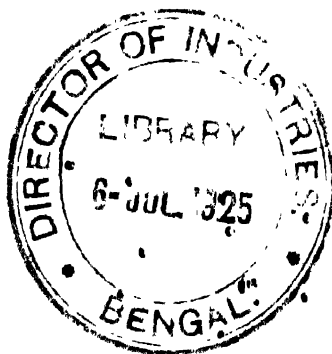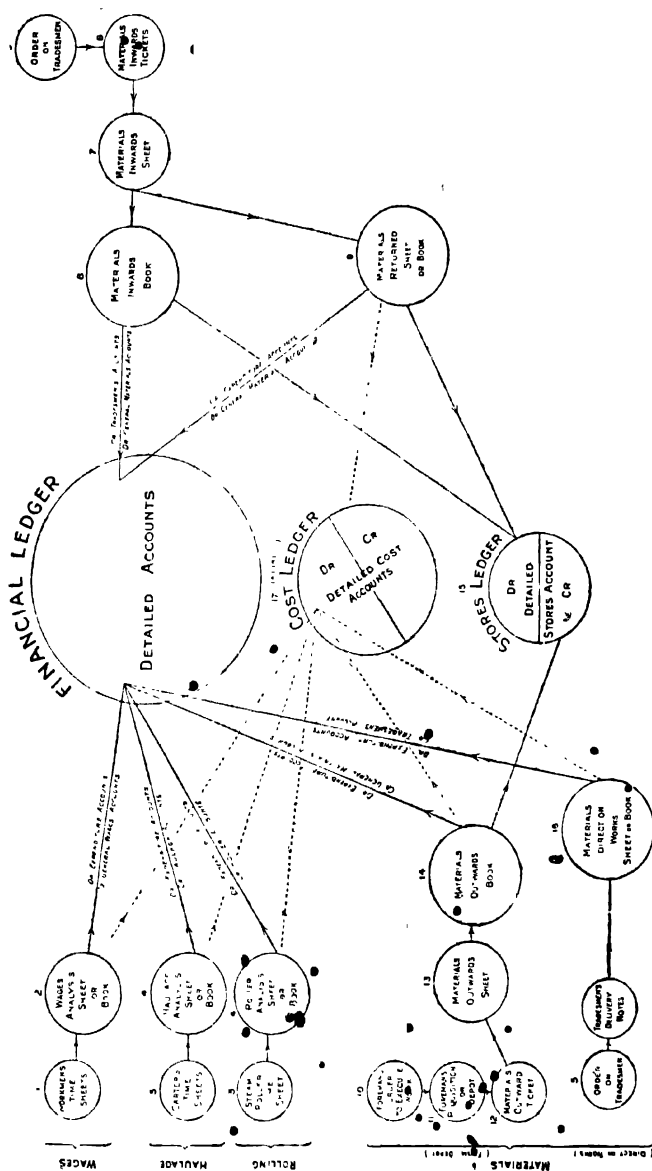
FIG. 123.—Suggested System of Highways Accounts

APPENDIX · I

BRITISH STANDARD NOMENCLATURE OF TARS, PITCHES, BITUMENS, AND ASPHALTES WHEN USED FOR ROAD PURPOSES

Introductory Remarks

THE materials now used by Road Engineers for binding together the stones and other mineral aggregate used to form road crusts and road surfaces may be conveniently divided into three groups. These are :—

1. The tars and pitches obtained by the destructive distillation of coal or similar substances.

2. The bitumens and asphaltes which are found in nature, or are obtained artificially from asphaltic oils.

3. Chemical binders, including the Portland and natural cements which owe their cementing value as road binders to chemical action, and which are not dealt with in the present report.

Hitherto the term " bituminous material " has been loosely applied to tar products as well as to bitumens and asphaltes, but the Committee have from the first considered that it was desirable from the Road Engineers' point of view to maintain a sharp line of demarcation between the two groups. The views put forward in correspondence from America and by American engineers of standing and experience have been carefully considered, but the Committee still adhere strongly to the view that the description " bituminous " should be applied only to the second group.

In this country the first group of road binders, the coal-tars and pitches, have been in use for many years, and as the Road Board in 1911 issued Specifications for the tars, tar oils, and pitches, which they recommended for road purposes, these materials have already to some extent been defined by those Specifications. The Road Board early in 1914 issued a second edition of these Specifications. Only two classes of tar and one class of pitch are dealt with, and as these Specifications are of such recent date, the Committee recom-

mend that they be adopted provisionally as the British Standard Specifications for Tars and Pitches used for Road Work.

The Committee find, that the choice of names for the second group of road binders is a matter of some difficulty. This difficulty is increased by the fact that whilst it is desirable to obtain the concurrence of the American Engineers to the nomenclature and definitions which the Committee now propose, the adoption of the American nomenclature for, the various materials composing this group would be liable to lead to confusion and misunderstanding in this country.

The Committee have been very anxious to secure uniformity with American practice, and have carefully and fully considered the definitions adopted by the American Society for Testing Materials and by the Committee of the American Society of Civil Engineers, put forward by the American corresponding members, but it is felt that the definitions now decided on are preferable from the Road Engineers' point of view, as they are based on those characteristics of the materials which can be most readily verified when employed for road-making.

In accordance with this view the Committee consider that it is desirable to make a sharp distinction between coal-tar and paraffin oil derivatives on the one side, and native bituminous substances and asphaltic oil residues on the other, and they are therefore unable to accept the American definition of Bitumen which would include the coal-tars.

Definitions.   First Group

Tar Products (Principally Coal Tar and Pitch)

Definition of Tar

1. Tar is the matter (freed from water) condensed from the volatile products of the destructive distillation of hydro-carbon matter, whether this be contained in coal, wood, peat, oil, etc.

Prefix denoting Source of Origin or Method of Production

2. A prefix such as " Coal," "Wood,", " Peat," " Gas Works," " Blast Furnace," " Coke Oven," etc., must be added to the word " Tar " to indicate the source of origin or method of production.

Definition of Pitch.

3. Pitch is the solid or semi-solid residue from the partial evapora- tion of tar.

Second Group

Bitumens and Asphaltes

Definition of Bitumen

4. Bitumen is a generic term for a group of hydro-carbon products soluble in carbon disulphide, which either occur in nature or are obtained by the evaporation of asphaltic oils. The term shall not include residues from paraffin oils or coal-tar products.

Note.—Commercial materials may be described as **Bitumen** if they contain not less than **98** per cent of pure **Bitumen** as defined above.

Definition of Native Bitumen

5. Native Bitumen is bitumen found in nature, carrying in suspension a variable proportion of mineral matter.

The term " Native Bitumen " shall not be applied to the residuals from the distillation of asphaltic oils.

Definition of Asphalte

6. Asphalte is a road material consisting of a mixture of bitumen and finely graded mineral matter. The mineral matter may range from an impalpable powder up to material of such a size as will pass through a sieve having square holes ¼ inch wide.

Definition of Native or Rock Asphalte

7. Native or Rock Asphalte is a rock which has been impregnated by nature with bitumen.

Prefixes denoting Source of Origin

8. The Committee recommend that for convenience of identification prefixes denoting geographically the source of origin should be attached to each of the four terms defined above.

Note.—*The Association desires to call attention to the fact that this Specification is intended to include the technical provisions necessary for the supply of the material herein referred to but does not purport to include all the necessary provisions of a Contract.*

BRITISH STANDARD SPECIFICATION FOR PITCH FOR ROAD PURPOSES

(Based upon the Road Board Specification No. 6 and published with the approval of the Road Board.)

Standard Pitch for Road Purposes in the United Kingdom shall be specified as follows :—

British Standard Specification for Pitch

General

1. This pitch is suitable for pitch grouting. See "Road Board General Directions for Pitch Grouting."

Consistency

2. The pitch is obtained of the required consistency most conveniently by running it off from tar stills in which the distillation of the tar has been stopped at the point at which the residual pitch will give a penetration of 70 (or such other penetration as may be specified to suit climatic or local conditions) when tested at 25° Centigrade (77° Fahrenheit) on a penetrometer. Harder pitch may be softened or cut back, in the still or in a mixer at the tar works, to the extent necessary for it to give this penetration, by the addition of tar oil of the grade specified below in Clauses 7 to 10.

Where pitch of the required consistency is not thus directly procurable, it may be prepared by softening commercial soft pitch, as specified below in Clauses 4 to 6, by the addition of tar oil as specified below in Clauses 7 to 10. In preparing the softened pitch in this manner the tar oil is added to the pitch in the manner described under "Instructions for Melting the Pitch" in the "Road Board General Directions for Surfacing with Pitch-Grouted Macadam," in such proportions that the resultant softened pitch will give a penetration of 70 (or such other penetration as may be specified to suit climatic or local conditions) when tested at 25° Centigrade (77° Fahrenheit) on a penetrometer, with a No. 2 needle weighted to 100 grams for five seconds.

Prepared Pitch from Tar Distilleries

General Characteristics

3. Pitch which has been procured of the required consistency directly from a tar distiller needs only to be thoroughly melted in the pitch heaters or boilers, but as a precaution against burning, 1 to 2 per cent of tar oil may advantageously be put into the boilers with the pitch.

Pitch which has been procured of the required consistency directly from a tar distillery shall not yield more than 4 per cent of distillate below 270° Centigrade, or 518° Fahrenheit, on distillation as described below in Clause 5, and shall contain not less than 16 per cent and not more than 28 per cent of "free carbon," as defined below in Clause 6:

Commercial Soft Pitch

Source of Pitch

4. The pitch shall be derived wholly from tar produced in the carbonization of coal, except that it may contain not more than 25 per cent of pitch derived from tar produced in the manufacture of carburetted water gas.

Fractionation

5. On distillation in a litre fractionating flask (a distillation flask without special fractionating column) one-half to two-thirds filled, the pitch shall yield the proportions by weight of distillates stated below ; the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask :—

Below 270° Centigrade or 518° Fahrenheit, not more than 1 per cent of distillate.

Between 270° and 315° Centigrade or 518° and 599° Fahrenheit, not less than 2 per cent and not more than 5 per cent of distillate.

Free Carbon

6. The pitch shall contain not less than 18 per cent and not more than 31 per cent by weight of free carbon. The free carbon is to be determined by the weight of the residue after complete extraction of all matter soluble in benzol or disulphide of carbon. The extraction is best carried out in a Soxhlet or similar apparatus by disulphide of carbon followed by benzol.

Tar Oil

Source of Tar Oil

7. Tar oil to be used is preferably a filtered green or anthracene oil, and shall be derived wholly from tar produced in the carbonization of coal or from such tar mixed with not more than 25 per cent of its volume of tar produced in the manufacture of carburetted water gas.

Specific Gravity

8. The specific gravity of the tar oil at 20° Centigrade (68° Fahrenheit) shall lie between 1·065 and 1·085.

Freedom from Naphthalene and Anthracene

9. The tar oil after standing for half an hour at 20° Centigrade (68° Fahrenheit) shall remain clear and free from solid matter (naphthalene anthracene, etc.).

Fractionation

10. The tar oil shall be commercially free from light oils and water. On distillation in a litre fractionating flask (a distillation flask without special fractionating column) one-half to two-thirds filled, the tar oil shall yield the proportions by weight of distillates stated below ; the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask :—

Below 170° Centigrade or 338° Fahrenheit, not more than 1 per cent of distillate (light oils and water, if any).

Below 270° Centigrade or 518° Fahrenheit not more than 30 per cent of distillate (middle oils, and light oils and water, if any).

Below 330° Centigrade or 626° Fahrenheit, not less than 95 per cent of distillate (heavy oils, middle oils, and light oils and water, if any).

ROADS DEPARTMENT SPECIFICATION
No. 3 (*a*) and 3 (*b*)
(FOR TARS No. 1 AND No. 2)

General

1. The tar shall be prepared in stills or dehydrating plant from tar produced in the carbonization of coal or produced in the use of coal in blast furnaces, except that the tar from which it is prepared may contain not more than 15 per cent of the tar produced in the manufacture of carburetted water gas.

2. The tar, when tested according to the methods described in Appendix " A," shall conform to the requirements specified under the appropriate heading, viz. 3 (*a*) for Tar No. 1 and 3 (*b*) for Tar No. 2.

3. Tar for the surface tarring of roads shall fall within the requirements specified under 3 (*a*) for Tar No. 1 and tar for making tarmacadam shall fall within the requirements specified under 3 (*b*) for Tar No. 2, but tars of which the consistency lies between 15 and 25 seconds must not be supplied for either purpose unless specifically allowed by the Surveyor responsible for the work in the terms of the contract or order for the tar. (Tars of which the consistency lies between 15 and 25 seconds usually need special conditions or special experience to ensure good results from them for either purpose.)

Surveyors may also, at their discretion, specify that the tar shall contain not less than 10 per cent of " free carbon," but this limitation will exclude some tars from Scotch sources and from certain

types óf carboni̇zing plant elṡewhe̟re, which have given satisfactory
results in the hands of those accustomed to their use.

4. SCHEDULE OF REQUIREMENTS

Requirements to be fulfilled on testing.	Specification No.	
	3 (a).	3 (b).
	Tar No. 1.	Tar No. 2.
Specific gravity at 15° C., not higher than	1·225	1·240
Water or Ammoniacal Liquor, not more than . . .	1·0 per cent by weight.	1·0 per cent by weight.
Other Distillate (*Light Oils*) *below* 170° C., not more than . .	1·0 per cent by weight.	
Distillate between 170° & 270° C. (*Middle Oils*), within the range .	12·0—24·0 per cent by weight.	10·0—18·0 per cent by weight.
Distillate between 270° & 300° C. (*Heavy Oils*), within the range .	4·0—12·0 per cent by weight.	6·0—12·0 per cent by weight.
Phenols or Crude-Tar-Acids, not more than	5·0 per cent by volume.	4·0 per cent by volume.
Naphthalene, not more than .	8·0 per cent by weight.	5·0 per cent by weight.
" *Free Carbon*," not more than .	22·0 per cent by weight.	24·0 per cent by weight.
Consistency or *Viscosity*, within the range	3·0—20·0 seconds.	20·0—100·0 seconds.

Analyst's Report

5. The results of the testing of the sample of tar shall be reported
by the analyst on the form of which a specimen is given in Appendix
" B."

Appendix " A "

Methods of Testing

1. The methods of testing which shall be used to ascertain if a
tar conforms to the requirements of the Roads Department Specifi-
cation are stated below in so far as they depart from ordinary
analytical practice, or need precise definition.

Specific Gravity

2. The specific gravity of the tar at 15° C. may be ascertained by the analyst by any trustworthy method, but for comparative purposes and to check the uniformity of deliveries sufficiently accurate results may be obtained very quickly by the use of Hutchinson's nickel-silver hydrometer, or "tar-gravity gauge," with temperature corrector.

Distillation

3. A distillation flask, of a nominal capacity of one litre and without special fractionating column, shall be one-half to two-thirds filled with a weighed quantity of the tar, which shall then be distilled. The flask shall be fitted with a standardized thermometer, graduated in degrees over a range of not less than 80° to 330° C. The top of the bulb of the thermometer shall be level with the lower edge of the opening of the side tube of the flask. The products of distillation up to a temperature of 200° C. shall be condensed by cooling with a cold-water condenser ; above that temperature the condenser-tube shall be used without the cold-water jacket.

· 4. The *distillate below* 170° *C.* shall be collected in a weighed measuring cylinder and weighed. The volume of *water* or *ammoniacal liquor* shall be read in the cylinder to the nearest half-cubic-centimetre, and—taking 1 c.c. of the water or liquor as equal to 1 gram —the percentages by weight of the water or ammoniacal liquor and of the *other distillate* (*light oils*) are calculated. (For Tar No. 2 it is unnecessary to ascertain separately the percentages of water and other distillate.)

5. The *distillate between* 170° *and* 270° *C.* (*middle oils*) shall be collected in a weighed vessel and weighed, and its percentage by weight calculated. This distillate shall be reserved for the determination of phenols and naphthalene.

6. The *distillate between* 270° *and* 300° *C.* (*heavy oils* shall be collected in a weighed vessel and weighed, and its percentage by weight calculated).

7. A valuable check on the result of the distillation is obtained by weighing the flask containing the residual pitch. The total of the weights of all the distillates and of the residual pitch should usually represent not less than 99 per cent of the weight of tar taken for the distillation.

Phenols

8. The phenols or crude-tar-acids shall be determined by bringing the whole of the distillate between 170° and 270° C. (middle oils) to a temperature of 40° to 50° C., adding to them about 20 per cent of solution of caustic soda having a specific gravity of about 1·20, and ·

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shaking vigorously every five minutes while keeping the mixture at
40° to 50° C. At the end of 15 minutes the mixture is poured into a
tap-funnel, and after the solution of caustic soda has settled out,
this solution is run off into a measuring cylinder. The extraction is
repeated precisely as before with the same amount of fresh solution
of caustic soda, which is separated and run off into the measuring
cylinder which contains the first extract. The contents of the
measuring cylinder are then made slightly acid by gradual addition
of hydrochloric acid. The volume of the phenols or crude-tar-acids
which are thereby liberated is read off, and their percentage on the
volume of the tar taken for the distillation is calculated.

Naphthalene

9. To determine the naphthalene, the distillate between 170° and
270° C. (middle oils), after separation of the phenols, is weighed,
warmed sufficiently to dissolve all the naphthalene in it, well
agitated, and an aliquot part—not less than 25 grams—taken.
This aliquot part is cooled to 15° C. and kept at that temperature
for half an hour. The naphthalene which has settled out is then
filtered off with the aid of a filter pump, and pressed between folds
of filter paper until all the oil has been removed by the paper. The
naphthalene is then weighed, and its percentage by weight on the
tar is calculated.

" Free Carbon "

10. Matter in the tar which is insoluble in benzol of the com-
mercial 90 per cent grade shall be reported as " free carbon," pro-
vided that not more than 10 per cent of this insoluble matter is
retained on a sieve of 80 holes to the linear inch.

11. The determination of " free carbon " may ordinarily be made
by either of the three methods described below, but in the event of
the result obtained by either of the other methods being above the
specified maximum, the determination shall be finally made by the
first method, and the result obtained by that method shall be
accepted as correct and conclusive. The three methods, if carried
out with due care, should give identical results. Either the first or
second method is usually preferred in works laboratories, while the
third is specially suitable for laboratories in which it is imperative
to avoid the greater fire-risk attendant on the use of a relatively
large quantity of benzol Whichever method is followed, the sample
of tar should be thoroughly stirred before the portion for the deter-
mination is drawn from it.

(i) *First Method.*—Two grams of the tar is mixed with cold
benzol, and, after the free carbon has settled out the benzol is
decanted off through a balanced pair of filter papers. The free

carbon is washed with benzol by decantation several times, and is then passed on to the filter, and washed with 500 c.c. of hot benzol. The total quantity of benzol used in the extraction shall be one litre. The filter papers and contents are dried and the " free carbon " is weighed.

(ii) *Second Method*.—Two grams of the tar is mixed in a small beaker with 25 c.c. of benzol, and the mixture is stirred while it is being heated to boiling. After it has boiled it is filtered through a Gooch crucible prepared in the usual way, and the beaker is washed out repeatedly with hot benzol until all its contents have been thereby transferred to the crucible. Cold benzol is then run slowly from a tap-funnel through the crucible until the quantity of benzol used in the extraction amounts in all to one litre. The " free carbon " is dried and weighed.

(iii) *Third Method*.—Between 9 and 11 grams of the tar is mixed in a small beaker with benzol, and the mixture is passed, by repeated washings of the beaker with benzol, into an extraction thimble, previously dried and counterpoised against a dried thimble previously extracted with benzol. The contents of the thimble are then completely extracted with benzol in a Soxhlet or similar apparatus (in which the thimble should not be quite submerged in the benzol), and the thimble is then dried and weighed against the dried counterpoise. The weight of its contents is taken as the weight of " free carbon." The total quantity of benzol used need not exceed 200 c.c.

Consistency

12. The consistency or viscosity is ascertained by the time, stated in seconds, taken by Hutchinson's Tar-Tester or Viscosity Gauge, No. 2 poise, to sink from the lower to the upper ring of the gauge, when it is placed in the tar while the latter is at a uniform temperature of 25° C. and is contained in a vessel of which the internal diameter is between 95 and 102 millimetres (i.e. $3\frac{3}{4}$ and 4 in.).

Sampling

13. A sample of tar for analysis should not be less than half a gallon (and if drawn from barrels should be from a massed sample taken from at least six barrels), and should be in a can or other vessel which, before filling, was both clean and dry inside.

Appendix " B "

Specimen of Standard Form on which Analysis of Tar is to be given.

Form No. 152 (Roads)

County....................

' Reference No..............

MINISTRY OF TRANSPORT
(Roads Department)

Particulars of Tar, to Roads Department Specification for work of grouting or coating material with tar, in connection with Application for Advances.

1. Origin of Tar (Gas, Coke Oven, or Blast Furnace Works, or Tar Distillery) ....
2. Temperature at which Dehydrating Plant is worked ....
3. Proposed use of Tar ; e.g. Grouting ; Coating ; or Surface Dressing ....

   Particulars of Analysis in accordance with Appendix " A " of Specification.
4. Specific Gravity at 15° C. ....
5. Water or Ammoniacal Liquor   .. Percentage by weight......
6. Other Distillate below 170° C.   .. Percentage by weight......
7. Distillate between 170° & 270° C... Percentage by weight......
8. Distillate between 270° & 300° C .. Percentage by weight......
9. Phenols or Crude-Tar-Acids   .. Percentage by volume......
10. Naphthalene   .. '   ..   .. Percentage by weight......
11. Free Carbon   ..   ..   .. Percentage by weight......
12. Consistency or Viscosity (Hutchinson) at 25° C...Seconds ......

APPENDIX II

ROAD DIRECTION POSTS AND WARNING SIGNS

Copy of circular addressed to the Clerks to County Councils, County Borough, County Burgh, Borough and Burgh Councils, District Committees and Urban and Rural District Councils, and other Highway Authorities in England and Wales and Scotland is given below.

MINISTRY OF TRANSPORT,
Roads Department,
7, Whitehall Gardens,
London, S.W. 1,
28th February, 1921.

Standardization of Road Direction Posts and Warning Signs

SIR,

I am directed by the Minister of Transport to state that he has had under consideration for some time the question of the desirability of standardizing, as far as possible, direction posts, warning notices, and other road signs used on public highways.

2. The authority for setting up sign or direction posts is derived from Section 24 of the Highway Act, 1835. Again, under Section 10 (2) of the Motor Car Act, 1903, the Local Government Board were empowered to make regulations prescribing the size and colour of sign posts denoting dangerous corners, cross roads, and precipitous places.

In the appendix to a Circular Letter dated 10th March, 1904 (S.R. and O., 1904, No. 315*) the Board gave details as to the size, shape, and colour of certain symbols for road signs, which had been jointly recommended for adoption by the County Councils Association and the Association of Municipal Corporations. In this circular letter the Board stated that if the recommendations of the Associations were carried out it would not be necessary for them to issue regulations upon the subject.

3. It is a matter of common knowledge that although the signs recommended by the Local Government Board in 1904 have been extensively adopted, a great variety of other signs and directions,

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both official and unofficial, have been placed by the sides of highways. The confusing information presented to-day by the variety and number of these signs has undoubtedly created a tendency among road users to disregard them. In the Minister's view this tendency can only be corrected by the general use of an approved series of standard signs, to which road traffic would readily become responsive, with a resulting increase in the convenience and safety of the travelling public.

4. With a view to arriving at some definite proposals which would meet with general acceptance, the Minister requested the County Surveyors' Society, towards the close of 1919, to appoint a special committee to consider and report on the general question of road signs and direction posts in the light of modern traffic development. The report of this Committee was carefully considered by the officers of the Ministry, and the views of the more important associations of road users and motor organizations were obtained. Certain definite proposals were then referred by the Minister to the Roads Advisory Committee, and accepted by them at their Meeting on November 23rd, 1920, as forming the basis of a scheme which might with advantage be placed before all highway authorities in the country.

5. The scheme referred to above is set out in detail in the attached memorandum. The Minister does not at this stage desire to do more than place the scheme before highway authorities with a strong recommendation that the proposed standard forms for direction posts and warning signs should be introduced by them as, and when, opportunities arise with due regard to economy, and in particular whenever they may propose to erect new direction posts and warning signs on roads under their control. If this policy is steadily pursued it may be hoped that these standard forms will in time obtain universal recognition, and that no other forms of notices will be found on land dedicated to public highways.

The Minister realizes that under existing legislation no power exists to prevent private individuals from placing unauthorized notices in their hedgerows, and on land abutting on the highway. At the same time he hopes that local authorities, without the introduction of fresh legislation, will be able to do much to discourage this practice, and to ensure that road users may come to depend for guidance on authorized road signs alone.

6. The selection of the points at which direction posts or danger signs should be erected will remain, as at present, within the discretion of the highway authorities, having regard to the characteristics of the particular roads and the nature and extent of the traffic upon them.

7. Particular attention may be drawn to a novel feature in the proposals. The classification of roads is now approaching com-

pletion, and when the schedules reach their final form it is intended to distinguish each first and second-class road by an individual number. Provision is made in the scheme for indicating the route numbers on the arms of direction posts, in the belief that the universal adoption of this practice would be of the greatest service to road users generally. Where the text and size of the lettering upon the arms of an existing direction post are otherwise suitable, the route number could be conveniently added and secured to the end of the direction arm by means of a sleeve connector and set screws.

8. In placing these proposals before highway authorities the Minister feels that he can confidently depend upon their support and co-operation, and he particularly wishes it to be understood that he is not advocating any wholesale replacement of serviceable signs at the present time, having regard to the heavy burden of local rates.

<div align="center">

I am, Sir,

Your obedient Servant,

H. H. PIGGOTT,

Assistant Secretary.

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RECOMMENDATIONS FOR THE STANDARDIZATION OF ROAD DIRECTION POSTS AND WARNING SIGNS

(N.B.—*The illustrative diagrams attached to this Memorandum should be studied in connection with the instructions given below.*)

The character of the road information which it is desired to present to the travelling public may be conveniently grouped under the following heads :—

<div align="center">

I.—Road Direction Posts.
II.—Warning Signs and Notices.
III.—Village and Place Name Signs.

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I.—Road Direction Posts

1. The careful selection of the most suitable position for the direction post is of great importance, so as to secure the maximum visibility on all the roads of approach. In certain cases it may be advisable to re-site existing posts to secure a more dominant position.

2. It is generally undesirable to mask the lower portion of the post in hedges or shrubs. The full length of the post should be visible wherever possible.

3. The projection of the direction arms over the roadway should be avoided.

4. The direction arms should be set at such angles on the head of

the post as to ensure that each arm shall lie along the immediate general direction of the road it is indicating.

5. In all cases the lower arms should indicate the more important road, and only the arms indicating the same road should be set in the same horizontal plane.

6. The top and bottom diameters or widths of the supporting posts, as figured upon the accompanying diagrams, are optional, but for new posts it is suggested that these dimensions should be taken as a guide.

7. Where the text and size of lettering upon the arms of an existing post are otherwise suitable, the route number may be conveniently added and secured to the end of the direction arm by means of a sleeve connector and set screws.

8. The length of arm for new direction posts will be mainly dependent upon the number of letters in the longest place name. Due regard should be had to the size of the route number, the spacing between words, and the proportions of the letters as figured on the diagrams.

Dimensions and Details Recommended for Standardization

(a) Height of arms from ground . { Minimum, 8 ft.
   Maximum, 9 ft.

(b) Length of arm, including route number
   (variable) . . . . . Minimum, 3 ft.

(c) Depth of arm . . . . . Minimum, 7 in.

(d) Separation between arms . . . Minimum, 3 in.

(e) Lettering, black block letters raised $\frac{1}{8}$ in. on a white ground :—

   For single line . . . . 3-in. letters.
   For double line . . . . $2\frac{1}{2}$-in. letters, $\frac{1}{2}$ in.
      space between lines.

(f) Post . . . . . . Painted plain white.

(g) Route numbers . . . . 4-in. block figures,
      raised $\frac{1}{8}$ in., in
      panel at end of
      arms.

   1st class roads . Black letter A and figures on white
      ground.

   2nd class roads . White letter B and figures on black
      ground.

(h) Precedence of routes . . . Lower pair of arms
      indicating the more
      important road.

(i) An indication shall be given on the post of the Highway Authority responsible for its maintenance.

(*j*) In all but exceptional cases the arm should be lettered on both sides, the nearest village being given first, then the nearest important town, followed by the terminal town where necessary. The mileage should be given in figures only, immediately following the place to which it refers, the lowest fraction being a quarter.

(*k*) Wherever possible, the direction post should be placed in such position as to be visible to traffic from all converging roads for a distance of at least one hundred yards.

(*l*) The Authority having control over the more important roads should be responsible for the provision and maintenance of the necessary direction posts at the road junctions.

(*m*) The distances on the direction arm should be measured from the (civic) centre of the town or village indicated.

(*o*) The colour of the supporting posts of road direction posts, and also the field of the arms, should be painted plain white. The bordering, letters, and figures should stand in relief ⅛ in. above the field and be painted black.

II.—Warning Signs and Notices

1. The value and position of all danger signs now existing should be most carefully reviewed in the light of the following recommendations, and all redundant or unnecessary signs withdrawn from use. It is believed that a few signs, in carefully selected positions, and intended definitely to control cases of real danger, will have a greater effect than the indiscriminate use of a large number of signs of varying shapes and colours.

2. Importance is attached to the careful selection of the site and the placing of the post clear of bushes or other obstruction to visibility and so that the full length of the supporting post is seen. Where a choice of position exists due regard should be paid to the background for showing up the sign. For this reason the diameter or widths of the post as shown on the diagram, while optional, are recommended for use.

3. The present signs, as recommended in the circular letter from the Local Government Board, dated 10th March, 1904, for " Speed Limit " (and its notices), " Prohibition," " Caution," and " Other Notices " should be retained.

4. *The red triangular sign indicating " Caution" should in future be used to mean " Danger," and should be referred to as the " Danger " sign.*

5. The special danger to be guarded against should be indicated by means of a clear and legible symbol, based on the international symbols as far as applicable, together with a clear and simple title in letters 2 in. high, upon a vertical plate 12 in. wide and 21 in. long to be attached to the post below the danger sign.

The list of dangers to be notified in this manner are as follows :—

"School,"
" Level Crossing,"
" Cross Roads,"
" Corner " and " Double Corner,"
" Steep Hill."

(See diagrams at the end. The signs for " Corner " and " Double Corner " are reversible for right or left turns respectively. The illustrations show a right-hand turn.)

The symbol should be regarded as the principal means of indicating the nature of the danger to be guarded against.

6. Cast iron is recommended for the material of which the plates should be constructed, with letters and details in relief. Flat enamelled sheet iron is not recommended owing to its liability to damage and defacement by stones.

7. In towns and suburban areas, where street lighting arrangements permit, the illumination of road signs would be desirable as far as this can be done conveniently.

8. At certain special danger points upon roads of the above character it may be found desirable by the Highway Authority to erect special illuminated signs of the glass-fronted, internally illuminated, type. In these cases, the red triangle and appropriate symbol, where used, should be enlarged to a uniform size of $1\frac{1}{2}$ times the standard size.

Dimensions and Details Recommended for Standardization

(a) Height to the under-side of the triangle from ground, 9 ft.

(b) Space between triangle and top of notice plate, 6 in.

(c) Size of notice plate over all, 12 in. wide, 21 in. high.
Upper portion containing symbol, 15 in. in height.
Lower portion containing text of notice, 6 in. in height.
2-in. letters with $\frac{1}{2}$-in. separation for two lines, $\frac{1}{4}$-in. margin all round.

Symbols to be of standard pattern only, as above, or as added to from time to time. To be raised $\frac{1}{8}$ in. and painted black on a white field.

(d) Height of lower edge of notice plate from ground, 6 ft. 9 in. No danger signs to be exhibited without symbols.

(e) All danger signs to be placed facing approaching traffic and on near side of road, and generally speaking should be set so as to display the full length of supporting post.

(f) They should be sited as closely as possible to a distance between 75 and 100 yd. from the object of danger or commence-

ment of the danger zone ; and, if possible, so placed that on either side of its position a length of roadway and margin is clear and free from any obstruction to view such as lamp-post, telegraph pole, tramway standard, tree, etc.
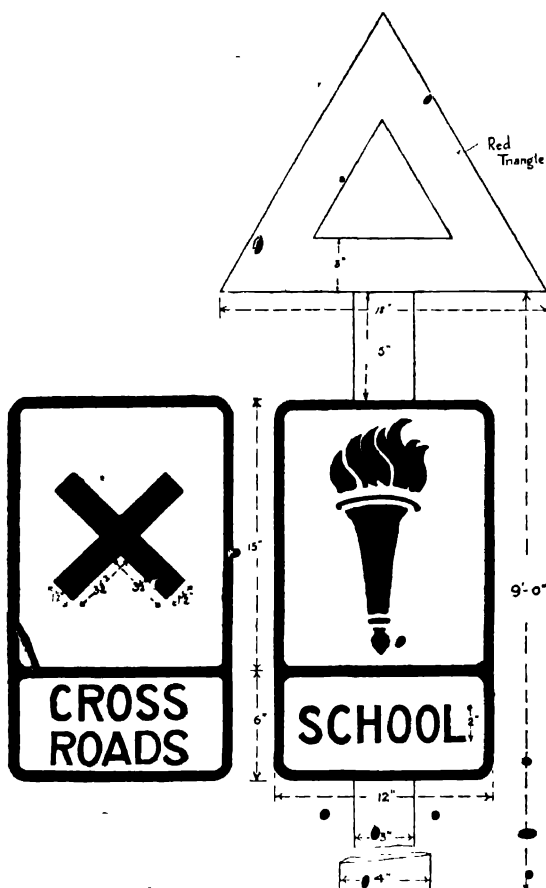
FIG. 124.—Danger Signs for Cross-Roads and Schools.

(g) All posts to which signs are affixed to be painted white, and to be iron or other suitable material and firmly embedded in the ground.

(h) Where there are direction posts at cross-roads and junctions in visible positions, it is recommended that " Cross Road" danger

signs are not necessary. The approaches to towns or villages also should need no warning sign, as such inhabited places are a sufficient indication in themselves that special care is necessary.

(*i*) The colour of the red triangle on the danger post should be what is known as " signal red," or " post office red."
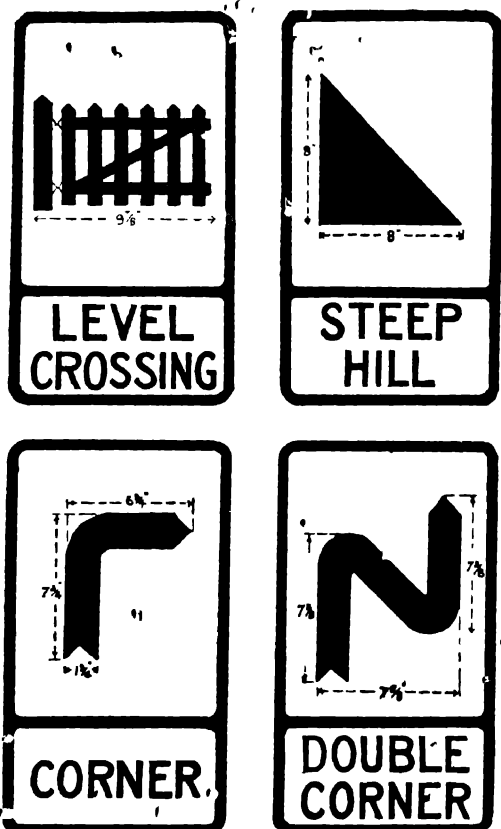
FIG. 125.—Danger Signs for Level Crossings, Steep Hills, and Corners.

The colour of the supporting posts of warning signs, and also the field of the plates, should be painted plain white. The bordering, letters, figures, and symbols should stand in relief $\frac{1}{8}$ in. above the field and be painted black.

III.—Village and Place Name Signs

1. It is generally agreed that it would be a great convenience to the travelling public if notices were erected on the main approaches to towns and villages, giving the name of the town or village. These name plates are recommended for adoption, where necessary. The plate can also conveniently carry the route number of the road upon which it is erected and the name of the county council or county borough council.

2. The width or diameter of the supporting post at top and bottom is optional, as is also its design, but it is recommended that these dimensions should not be substantially less than those figured upon the diagram annexed hereto. The form and proportion of the letters will, of course, determine the length of the plate. Certain place names of more than average length, e.g. two long words with a hyphen between, could be conveniently arranged in two lines.

The size of letter given in the accompanying diagram should always be regarded as a minimum.

Dimensions and Details Recommended for Standardization

(a) Height to centre of name on plate, 7 ft. (minimum).

(b) Height of letter, 6 in. To be raised, painted black on white field, down stroke to equal twice the width of up stroke, $1\frac{1}{2}$ in. to 2 in. clearance top and bottom. Route numbers to be in 3-in. letters. Council's title in $1\frac{1}{2}$-in. letters.

(c) To be sited on near side of road facing approaching traffic and at a distance of approximately 100 yd. or thereabouts from the first house of the village or town.

(d) The colour of the supporting posts and also the field of the sign should be painted plain white. The letters and figures should stand in relief $\frac{1}{8}$ in. above the field and be painted black. The colour used to denote the name of the highway authority on the sign is optional.
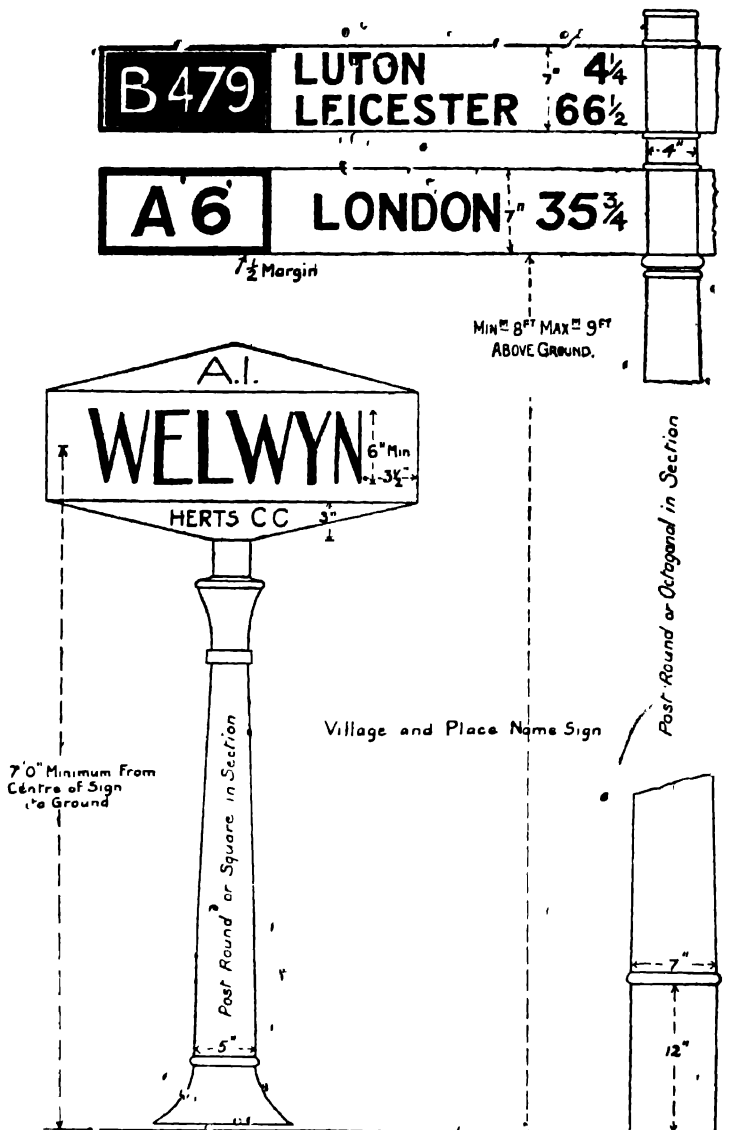
FIG. 126.—Signposts for Classified Roads and for Villages.

APPENDIX III

ROAD LEGISLATION

THE following list summarizes the principal road legislation which has been issued from time to time in this country and particularly that of recent origin :—

Motor Cars Act (Circular) 1896, 1903.
Locomotives on Highways (Circular) 1898.
Motor Cars Act, 1903.

Circular, October 16th, 1907, to all County Councils except the L.C.C. regarding signs, hedges, trees, etc. Registering Authorities in the U.K.

Ministry of Transport Act, 1919

This Act relates to the setting up of the Ministry of Transport. It defines the powers and duties of the Minister in connection with railways, bridges, extraordinary traffic, omnibus routes, acquisition of land, etc. It also refers to the appointment of a roads advisory committee. Under this Act, Sir Henry Maybury was appointed Director-General of Roads, and Divisional Engineers were afterwards appointed for certain areas of the country.

Roads Act, 1920

This Act deals chiefly with the taxation and licensing of the various classes of road vehicles and the establishment of the Road Fund. It marked the advent of the method of taxation based upon horse-power.

BIBLIOGRAPHY

American Highway Engineers' Handbook. By Arthur H. Blanchard. Probably the most comprehensive and up-to-date book on Highway Engineering. Published in 1919.

Bibliography of Road-making and Roads in the United Kingdom. By Dorothy Ballen, with an Introduction by Sir George Gibb, Chairman of the Road Bo. rd.

British Standard Nomenclature of Tars, Pitches, Bitumens, and Asphaltes when used for Road Purposes, and British Standard Specifications for Tar and Pitch for Road Purposes.

Concrete in Highway Construction. By Sanford E. Thomson.

Concrete Roads and their Construction. Compiled for Municipal Surveyors.

Design of Highway Bridges. By Milo S. Ketchum.

Digest of Highway Cases. By J. E. R. Stephens, Barrister-at-Law.

Dustless Roads : Tar Macadam. A Practical Treatise for Engineers, Surveyors, and others. By J. Walker Smith, M.Inst.C.E.

Earthwork Slips and Subsidences upon Public Works. Their Causes, Prevention, and Reparation. By John Newman, Assoc.M.Inst. C.E.

Elements of Highway Engineering. By Arthur H. Blanchard, C.E. (A.M.), Professor in Charge of the Graduate Course in Highway Engineering in Columbia University, in the City of New York, Consulting Highway Engineer, etc. etc.

Footpaths : Their Maintenance, Construction, and Cost. By A. Taylor Allen, C.E., Engineer and Surveyor, Portslade-on-Sea. With illustrations, diagrams, etc.

Glossary of Road Terms, A. By H. Percy Boulnois.

Highway Accounts : A Practical Costing System Applied to Highways Administration. By John W. Blakeborough.

Highway Construction. A Practical Guide to Modern Methods of Road Building and the Development of Better Ways of Communication. By T. Austin Byrne and Alfred E. Phillips.

Highways Inspectors' Handbook. By Prevost Hubbard.

BIBLIOGRAPHY 273

Law of Highways. Being the Law of Highways, Main Roads, Streets, and Bridges. By Wm. W. Mackenzie, M.A., Barrister-at-Law. The standard book on the subject.

Law and Practice of Private Street Works, The. Together with an Appendix containing Particulars and Decisions of Cases Reported. By William Spinks, M.Inst.C.E.

Law Relating to Highways, The. By H. Hampton Copnall, Solicitor, Clerk of the Notts County Council.

Making of High Roads, The. By Alfred Edward Carey. With an Appendix of Tables and Specifications.

Modern Asphalte Pavement, The. By Clifford Richardson.

Modern Road Construction. A Practical Treatise for the Use of Engineers, Students, etc. By Francis Wood, M.Inst.C.E.

Modern Roads. By H. Percy Boulnois, M.Inst.C.E., F.R.San.Inst., Past-President of the Institution of Municipal and County Engineers, late City Engineer of Liverpool, late Deputy Chief Engineering Inspector of the Local Government Board, etc.

Natural Rock Asphaltes and Bitumens : Their Geology, History, Properties, and Industrial Application. By Arthur Danby, Chemist and Public Consultant on Rock Asphalte and Bitumen.

New Streets : Laying-out and Making-up. By A. Taylor Allen, C.E.

Practical Roadwork. By H. T. Wakelam, M.Inst.C.E., F.G.S. 104 pages of letterpress and 14 photographic illustrations.

Private Street Works, The Law relating to, under the Act of 1892. By W. Carlyle Croasdell, Barrister-at-Law.

Quantities : Roadmaking and Sewer Construction for the Use of Surveyors. By J. Bartlett, M.S.A.

Road Board Specification for the Tar Treatment of Roads,

Road Construction and Maintenance, Compiled at the School of Military Engineering. By Major E. M. Paul, R.E., Assoc.Inst. C.E.

Roads and Pavements, The Construction of. By T. R. Agg.

Streets, Roads, and Pavements. By H. Gilbert Whyatt.

Street Pavements and Paving Materials. A Manual of City Pavements : The methods and materials of their Construction. For the use of Students, Engineers, and City Officials. By Geo. W. Tillson, C.E., Consulting Engineer to the Borough President, Borough of Brooklyn, M.Am.Soc.C.E.

Streets of To-day and To-morrow. By Guy Wilfred Hayler.

R.E.—

Tables for Facilitating the Calculation of Earthworks. By David Cunningham, C.E.

Tables for Setting Out Curves from 10 ft. to 5000 ft. Radius. By H. A. Cutler and F. J. Edge.

Tarred Granite Macadam : Is it a Failure ? Being the most Authoritative Exposition of the Views of County and other Road Engineers and Manufacturers as to the Claims of this Material.

Papers in the Proceedings of Inst. C.E. and Amer. Soc. of C.E.

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